In a recent communication, Patel et al. presented appropriate use criteria (AUC) for diagnostic catheterization (DC) that were developed by a group of clinicians representing the American College of Cardiology Foundation, the Society for Cardiovascular Angiography and Interventions, and several other professional societies. The AUC were based, in part, on the results of earlier studies that identified the relationship between the presence of significant and severe coronary artery disease (CAD) and various demographic, clinical and symptomatic factors.

The AUC for DC that pertain to CAD assessment are separated into 7 broad categories:

- Suspected or known acute coronary syndrome
- Suspected CAD: no prior noninvasive stress imaging (no prior percutaneous coronary intervention [PCI], coronary artery bypass graft [CABG] surgery, or angiogram showing ≥50% angiographic stenosis)
- Suspected CAD: prior noninvasive stress imaging (no prior PCI, CABG, or angiogram showing ≥50% angiographic stenosis),
- Adjunctive invasive diagnostic testing in patients undergoing diagnostic coronary angiography
- Known obstructive CAD
- Arrhythmias
- Preoperative coronary evaluation for noncardiac surgery in stable patients

The RAND methodology used for the development of other appropriateness criteria was then used to rate patients as appropriate, uncertain, or inappropriate for DC. The clinical scenarios differ as a function of the broad category in which a patient is classified.
WHAT IS KNOWN

• Recently, professional societies published appropriate use criteria for diagnostic cardiac catheterization.

WHAT THE STUDY ADDS

• This article applies the appropriate use criteria for diagnostic cardiac catheterization to a population of patients with suspected coronary artery disease.

• Our study demonstrates a relatively high rate of inappropriateness (24.9%) in a population of New York State patients.

For example, for suspected CAD: prior noninvasive stress imaging, the clinical characteristics used for classification purposes are symptoms (asymptomatic, symptomatic) and stress test findings (low risk, intermediate risk, high risk, discordant, or equivocal), whereas for suspected CAD: no prior noninvasive stress testing, the characteristics are asymptomatic/global CAD risk and symptomatic/pretest CAD probability.1 The panel convened by the American College of Cardiology Foundation and the other societies used a Delphi process to assign appropriateness ratings based on the degree of consensus resulting from the process.1

This study applies the 2 sections of the new DC AUC related to suspected CAD noted above (suspected CAD: no prior noninvasive testing and suspected CAD: prior noninvasive testing) to a New York State database consisting of patients who underwent DC with or without prior stress testing. The purposes of the study were to examine the percentages of patients who were appropriate, uncertain, and inappropriate and to assess variations among hospitals in appropriateness rates. Also, the relationships between numerous baseline patient characteristics and appropriateness were explored, as well as the hospital-level relationship between inappropriateness for DC and other hospital-level variables, namely hospital volume of DC and inappropriateness rate for PCI.

Methods

Data

The primary database used in the study was New York State’s Cardiac Diagnostic Catheterization Database (CD2), a voluntary data system in New York maintained by the New York State Department of Health. For patients undergoing cardiac catheterization in a subset of 18 hospitals in New York, the database contains information on demographics, peripheral vascular disease, cerebrovascular disease, comorbidities, payer, angina type and class, stress test results (area of viable myocardium at risk), type of stress test (ECG or stress test with imaging), previous myocardial infarction, previous revascularization procedures, ejection fraction, ongoing ischemia, vessels diseased, congestive heart failure, diabetes mellitus, shock, and hemodynamic instability. The database also contains a data element indicating whether suspected CAD is the primary indication for the DC.

Completeness of data reporting is monitored by matching CD2 to New York’s acute care hospital discharge database, the Statewide Planning and Research Cooperative System and the Department of Health’s Ambulatory Surgery Database with New York’s PCI Registry (the Percutaneous Coronary Interventions Reporting System), and identifying cases reported with a DC in those databases that were not reported to CD2. Hospitals are required to provide data for those missing cases. Also, missing or invalid data elements are returned to hospitals for review and correction on an ongoing basis.

AUC ratings for patients in the study (patients with suspected CAD) were based on combinations of global risk score, pretest probability of CAD, stress test findings; the presence/absence of symptoms; and in the case of intermediate-risk stress test findings, on the type of stress test (ECG versus imaging). Definitions for these data elements were provided to hospitals in a data dictionary, and these definitions are identical to those in the DC AUC document.1

This study is approved by University at Albany, State University of New York institutional review board, and as registry-based retrospective study, it did not require informed consent from the study subjects.

Patients and Hospitals

Candidates for the study were 12,252 patients who underwent DC procedures between January 1, 2010, and June 30, 2011, for suspected CAD in the 18 nonfederal New York hospitals in CD2 who did not have acute coronary syndrome or arrhythmia; a history of previous coronary catheterization, PCI, CABG, or valve surgery; or a significant valvular pathology. Patients undergoing DC were consecutively enrolled in all but 5 of the 18 hospitals; for these hospitals, the first 100 cases in each month were consecutively enrolled, and then the remaining patients enrolled in that month were limited to minority patients. To assess potential bias resulting from patients not being consecutively enrolled in these 5 hospitals, appropriateness rates were recalculated after limiting patients to the first 100 in each month. Because the resulting rates were within one tenth of 1% of the original rates, they are not reported in the results.

Patients in the study comprised 33.1% of all patients undergoing DC in the 18 hospitals. Patients who could not be rated for appropriateness were then excluded from the candidates. Among patients with a prior stress test, these were patients who did not have a well-defined risk category based on stress test findings (ie, a positive test result without further grading of risk level, 1619 patients), who had indeterminate stress test findings (249), who had unavailable stress test results (180), who had missing values for left ventricular ejection fraction (640), and who underwent computed tomographic coronary arteriography (472). Among patients without a prior stress test, patients who could not be rated were symptomatic patients with missing information on chest pain type (296). The total number of mutually exclusive exclusions for these reasons was 3266, resulting in a final study sample of 8986 patients (see Figure 1 for exclusions).

Statistical Analysis

All patients in the study were rated as appropriate, uncertain, or inappropriate. The numbers of patients with each rating were summed across all scenarios so that the percentage of patients undergoing each of the procedures who were appropriate, uncertain, and inappropriate could be determined. Ratings were also examined by individual scenarios contributing to the overall appropriateness rating so that the scenarios most responsible for the overall results could be identified.

Demographic and clinical risk factors were then examined by appropriateness category by using a generalized estimating equation model to test the bivariate relationship between each risk factor and the appropriateness rating (inappropriate versus
Also, because measures such as global CAD risk and pretest probability of CAD were used in the DC AUC for patients without prior noninvasive testing, these measures were compared across appropriateness categories. Although global CAD risk could not be captured as defined initially, the modified version presented by Patel et al (1 point imputed for dyslipidemia and hypertension) was used.

Analyses were also conducted to determine the range across hospitals and across operators in appropriateness ratings. The extent of variations in rates of appropriateness was examined by calculating means, medians, interquartile ranges, and maximum and minimum percentages for each of the appropriateness ratings. Median odds ratios were obtained by developing a hierarchical logistic regression model with only patient-level variables included, without including variables that were directly related to appropriateness (global risk score, pretest probability, symptom status, stress test results). The median odds ratio is the median value of the adjusted odds of inappropriateness between each pair of hospitals, where the odds is expressed as the odds of the hospital with higher inappropriateness to the odds of the hospital with lower inappropriateness.

Also, the hospital-level relationship between inappropriateness for DC and hospital volume was investigated using the Spearman correlation coefficient. Hospitals’ percentages of inappropriate DC for patients with suspected CAD were compared with their inappropriateness rates for PCI among patients without acute coronary syndromes or previous CABG surgery using results from an earlier study for the latter measure using the Spearman correlation coefficient.

**Results**

Of the 8986 patients who could be rated for appropriateness, 3169 (35.3%) were rated as appropriate, 3577 (39.8%) were rated as uncertain, and 2240 (24.9%) were rated as inappropriate (Table 1). Table 1 indicates that patients ≤55 years of age; women; current tobacco users; patients without diabetes mellitus, hypercholesterolemia, hypertension history, and angina symptoms; and patients with congestive heart failure, renal failure, low risk or no stress test results, and low global risk score were more likely to undergo inappropriate catheterizations than their counterparts. The inappropriateness rate across payers was quite consistent, with a range from 24% for Medicare to 31% for self-pay (with only 5% of the patients). Except for the small group of self-pay patients, other payers had rates that were close to the Medicare inappropriateness percentage. Patients with payers that were private, Medicaid, and other had 25% inappropriateness rates. To examine regional differences, the state was subdivided into 5 regions, and the range for inappropriateness was between 22% and 31%.

For each scenario associated with patients undergoing DC for suspected CAD, Table 2 presents the appropriateness ratings and the number and percentage of patients in that scenario. The scenarios for suspected CAD were all contained in 2 tables in the AUC, one denoting patients with a previous...
stress test and the other, patients without a previous stress test. For patients with a previous stress test, the nature of the findings (high risk, intermediate risk, or low risk) and the presence/absence of symptoms were used in the AUC to rate appropriateness. For patients without a previous stress test with symptoms, the pretest probability (low, intermediate, high) was used to rate appropriateness, and for patients without a previous stress test without symptoms, the global CAD risk (low, intermediate, high) was used for AUC ratings.

As noted in Table 2, patients who were rated as inappropriate were in 3 scenarios: (1) no previous stress test/asymptomatic (low or intermediate global CAD risk, 1270 patients (57% of all inappropriate DCs), (2) no previous stress test/symptomatic/low pretest probability, 163 patients (7% of all...
inappropriate DCs), and (3) previous stress test with low-risk findings/asymptomatic, 807 patients (36% of total inappropriate DCs). Thus, approximately two thirds of the patients rated by the AUC who underwent DC and were rated as inappropriate were patients without stress tests who had either low/intermediate global CAD risk or low pretest probabilities. The 3 groups of patients who were rated as appropriate were symptomatic patients with no previous stress test but high pretest probabilities of CAD (47.2% of all appropriate patients), symptomatic patients with intermediate-risk stress tests (36.7%), and patients with high-risk stress tests, regardless of symptoms (16.1%).

Figure 2 presents the range in appropriateness ratings across the 18 hospitals in the study. The median hospital appropriateness rate was 30.5%, with an interquartile range between 21.3% and 40.9%, a maximum of 62.6%, and a minimum of 11.8%. For inappropriateness ratings, the median hospital rate was 28.5%, with an interquartile range between 16.9% and 35.3%, a maximum of 48.8%, and a minimum of 8.6%. The median odds ratio was 1.86 (95% confidence interval, 1.39–2.26).

Figure 3 presents the range in appropriateness ratings across the 92 operators in the study with DC volumes of ≥25. The median operator appropriateness rate was 33.2%, with an interquartile range between 25.6% and 45.9%, a maximum of 67.3%, and a minimum of 7.7%. For inappropriateness ratings, the median operator rate was 24.6%, with an interquartile range between 16.5% and 32.4%, a maximum of 54.3%, and a minimum of 3.1%. A total of 23 (25%) operators had inappropriateness rates between 30% and 40%, and 8 (8.7%) had inappropriateness rates of ≥40% (Figure 4). The median odds ratio was 1.63 (95% confidence interval, 1.48–1.78).

Figure 5 examines the relationship between hospital DC volume and inappropriateness of DC among patients with suspected CAD. The correlation between these 2 variables was R=−0.36 (P=0.15). Figure 6 compares the inappropriateness for PCI among patients without acute coronary syndromes or

### Table 2. Angina Symptoms and Stress Test Result for Diagnostic Catheterization, Stratified by Appropriateness

<table>
<thead>
<tr>
<th>Previous Stress Test?</th>
<th>Stress Test Findings</th>
<th>Symptoms?</th>
<th>Global CAD Risk</th>
<th>Pretest Probability</th>
<th>Rating</th>
<th>No. (%) of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>NA</td>
<td>No</td>
<td>High</td>
<td>NA</td>
<td>U</td>
<td>329 (3.7)</td>
</tr>
<tr>
<td>No</td>
<td>NA</td>
<td>No</td>
<td>Low/intermediate</td>
<td>NA</td>
<td>I</td>
<td>1270 (14.1)</td>
</tr>
<tr>
<td>No</td>
<td>NA</td>
<td>Yes</td>
<td>NA</td>
<td>High</td>
<td>A</td>
<td>1495 (16.6)</td>
</tr>
<tr>
<td>No</td>
<td>NA</td>
<td>Yes</td>
<td>NA</td>
<td>Intermediate</td>
<td>U</td>
<td>1297 (14.4)</td>
</tr>
<tr>
<td>No</td>
<td>NA</td>
<td>Yes</td>
<td>NA</td>
<td>Low</td>
<td>I</td>
<td>163 (1.8)</td>
</tr>
<tr>
<td>Yes</td>
<td>High risk</td>
<td>Yes or No</td>
<td>NA</td>
<td>NA</td>
<td>A</td>
<td>510 (5.7)</td>
</tr>
<tr>
<td>Yes</td>
<td>Intermediate risk</td>
<td>Yes</td>
<td>NA</td>
<td>NA</td>
<td>A</td>
<td>1164 (13.0)</td>
</tr>
<tr>
<td>Yes</td>
<td>Intermediate risk</td>
<td>No</td>
<td>NA</td>
<td>NA</td>
<td>U</td>
<td>715 (8.0)</td>
</tr>
<tr>
<td>Yes</td>
<td>Low risk</td>
<td>Yes</td>
<td>NA</td>
<td>NA</td>
<td>U</td>
<td>1236 (13.8)</td>
</tr>
<tr>
<td>Yes</td>
<td>Low risk</td>
<td>No</td>
<td>NA</td>
<td>NA</td>
<td>I</td>
<td>807 (9.0)</td>
</tr>
</tbody>
</table>

A indicates appropriate rating; CAD, coronary artery disease; I, inappropriate rating; NA, not applicable (ie, not used to rate appropriateness in the given scenario); and U, uncertain rating.
prior CABG surgery with inappropriateness for DC among patients with suspected CAD after removing only the hospital with DC and no PCI. The correlation between these 2 variables was $R=0.20$ ($P=0.44$).

**Discussion**

The American College of Cardiology Foundation and several other professional societies have recently issued AUC for DC. The document is particularly timely and valuable given information from other recent studies that demonstrate the need for more cost-effective use of catheterization laboratory procedures. For instance, a recent study has demonstrated that only approximately one third of patients without known disease who underwent elective cardiac catheterization had obstructive coronary artery disease. Another study found that the rate of DCs per capita in New York is roughly twice as high as the rate in Ontario, and a follow-up to that study found that DC patients in Ontario were significantly more likely to have CAD and characteristics associated with CAD than their counterparts in New York.

The AUC for DC are separated into different types of patients, and our study concentrates on the subset of the patients who are considered for the procedure because of suspected CAD. Patients with no prior noninvasive testing were rated as inappropriate if they were asymptomatic with either a low or intermediate global risk score or if they were symptomatic with a low pretest probability of CAD. Global risk score is computed using age, sex, cholesterol, blood pressure, and smoking status, using a modified version that substitutes 1 point for hyperlipidemia and 1 point for hypertension. Pretest probability of CAD is a function of age, sex, and type/severity of symptoms. Patients with prior noninvasive testing...
were rated as inappropriate if they were asymptomatic and had low-risk stress test findings.

Of the 12,252 patients with suspected CAD, 27% were excluded, with roughly half excluded because the detailed stress test results were not known by the hospital, although the results were known to be positive. Thus, although the appropriateness criteria require more detailed information to determine appropriateness, the procedure was performed without accessing this information. A total of 2,240 (24.9%) of the 8,986 patients in the study group who could be rated were rated as inappropriate. Another 3,577 (39.8%) of the patients were rated as uncertain, and the remaining 3,169 (35.3%) were rated as appropriate. These results are more heavily weighted toward inappropriate than the findings of 3 earlier studies of the appropriateness of PCI versus medical therapy for elective patients mentioned above.13,16,17 For example, in the New York study, 28% of elective PCI patients could not be rated because of missing stress test information, and of the patients who could be rated, 14% were inappropriate, 50% were uncertain, and 36% were appropriate.13 However, the other studies were for appropriateness of PCI, and ours is the first study we are aware of that measures appropriateness of DC using the new AUC.

It is notable that 50.7% of all patients who could be rated had no stress tests before DC, and 31.5% of patients with no stress test results were rated as inappropriate for DC (Table 1). These patients comprised 64% of all patients with suspected CAD who were rated as inappropriate for DC. The vast majority of these patients (89%) were asymptomatic with low or intermediate global CAD risk scores. For asymptomatic patients without stress tests, the AUC are based on global CAD risk, and even a high global CAD risk is rated as only

Figure 5. Relationship between hospital volume and hospital rate of inappropriate diagnostic catheterization: New York, 2010 to 2011. \( R = -0.36 \) (\( P = 0.15 \)).

Figure 6. Relationship between hospital rates of inappropriate percutaneous coronary intervention (PCI) and inappropriate diagnostic catheterization: New York, 2010 to 2011. \( R = 0.20 \) (\( P = 0.44 \)).
uncertain. The remaining 11% of patients without a stress test who were rated as inappropriate were symptomatic but had low pretest probabilities of CAD.

For the 49.3% of patients with a previous stress test, a total of 18.2% were rated as inappropriate for DC, and patients with a previous stress test comprised 36% of all patients with suspected CAD who were rated as inappropriate for DC. All of these patients were asymptomatic with low-risk stress test findings, and the AUC for these patients was based entirely on symptoms and stress test findings.

There was a considerably large interhospital practice pattern variation in appropriateness rates. Hospitals’ appropriateness rates ranged from 11.8% to 62.6%, with an interquartile range of 21.3% to 40.9%, a mean of 33.1%, and a median of 30.5%.

Hospitals’ percentages of inappropriate DCs varied from 8.6% to 48.8%, with an interquartile range of 16.9% to 35.3%, a mean of 27.4%, a median of 28.5%, and a median odds ratio of 1.86 (95% confidence interval, 1.39–2.26). This means that for each pair of patients with identical clinical characteristics undergoing DC for suspected CAD, each from a randomly selected hospital, there is an 86% greater odds that one of the patients would receive an inappropriate DC than the other patient. The fact that the lower limit on the 95% confidence interval for the median odds ratio exceeds 1 means that there is a significant variation between hospitals. This level of variation suggests that the criteria for determining which patients should undergo DC differ considerably across hospitals, and the hospital in which a patient is in is much dependent on the chances of being referred for DC. However, it should be noted that the odds ratio overestimates the rate ratio when the prevalence rate is relatively high, so the median ratio of hospital rates of inappropriateness will be somewhat lower than the odds ratio.

The hospital-level relationship between total DC volume and the inappropriateness rate for DC among patients with suspected CAD was relatively weak ($R=−0.36; P=0.15$). The relationship between hospital inappropriateness rates for PCI and DC was also weak ($R=0.20; P=0.44$). It should be noted that the relationship was investigated only for certain types of DC and PCI patients (DC for suspected CAD, PCI for patients with stable CAD without prior CABG surgery), and the strength of the relationship may have been different with other types of patients or with all patients undergoing these procedures. However, the current findings suggest that decision making surrounding the use of the 2 procedures may be entirely different with regard to adherence to appropriateness criteria.

In an earlier study in New York, we found high rates of inappropriateness in the use of PCI.13 These results were provided to each hospital with their own results and how they compared with the state as a whole. Details were also given to hospitals regarding the inappropriateness rates for individual operators and inappropriateness rates for each scenario in the revascularization AUC and for various patient characteristics/risk factors. Although we do not have complete audited results for the effect of this initiative, it seems as if there has been a large decrease in inappropriateness rates. We plan to adopt this same strategy for reducing rates of inappropriateness for DC.

There are a few caveats to the study. With respect to the appropriateness findings, it should be noted that the AUC were published after the time frame used for the study, so no referring physicians had the opportunity to use the criteria in determining which patients to refer for DC. This is particularly important because appropriateness criteria and guidelines for DC have not been available for many years, so it is not surprising that there is substantial variation in the criteria used by referring cardiologists. Also, the findings are dependent on the accuracy of reported symptoms, and the process of reporting symptoms is fraught with potential error. As is noted in the AUC document, there is also variability in the interpretation of many noninvasive tests. The variation in hospital appropriateness rates could be, at least in part, because of differences in reporting both symptoms and noninvasive test results.

With regard to the volume appropriateness findings, we had access to total DC volume for the hospitals in the study but did not have access to total volume of DC cases who were candidates for the study. In particular, we did not have access to number of patients in each hospital minus the exclusions (acute coronary syndrome or arrhythmia; a history of previous coronary catheterization, PCI, CABG, or valve surgery), and the results may have been different if we had been able to use this more relevant volume measure.

Furthermore, the findings reported in the study are based on 18 hospitals in New York State and are based on a subset of patients undergoing DC in those hospitals (patients with no prior CABG, PCI, myocardial infarction, or CAD who have suspected CAD). Of the 18 DC hospitals in our database, 17 are certified to perform PCI, whereas 39 of the 82 DC hospitals in the state are certified to perform PCI. Thus, to the extent that ability to perform PCI may affect DC appropriateness, our result may not be representative. Unfortunately, we do not have access to patient-level data from DC hospitals not in the CD2. Because of the restriction to patients without prior CABG, PCI, myocardial infarction, or CAD in the 18 hospitals, only $\approx33\%$ of all DC patients in those hospitals were included in the study. If all other patients undergoing DC in the hospitals were appropriate for the procedure, the overall inappropriateness rate would have been 8.3%.

Also, using an aggregate DC database from the entire state that does not contain detailed DC information, we estimate that $\approx16\%$ of all DC cases in the state were contained in our DC database before exclusions for type of DC (done for suspected CAD) and missing information. It is an open question as to whether similar results would have occurred if we had access to data from the entire state or from other regions of the country.

Another caveat is that of the 12,252 patients who were examined to determine appropriateness of DC, a total of 3,266 patients (27%) could not be rated because they were missing information required to determine appropriateness. The main reasons for this were a positive stress test without information as to the level of risk (high, intermediate, low) and absence of information on patients’ ejection fractions. It is possible that if this missing information had been available, the inappropriateness rate would have been either higher or lower. In the unlikely event that all of these patients with missing...
information were appropriate for DC, the inappropriateness rate would have dropped from 24.9% to 18.3%.

In addition, the application of AUC to individual clinical decisions is complicated because the criteria cannot possibly capture every important consideration. Clearly, there are individual cases that fall outside of the criteria, and any attempt to monitor appropriateness should be cognizant of this reality and allow for exceptions.

It should also be noted that AUC for DC and PCI are an evolving process, and a new nomenclature change has been approved but not yet published. This could have a bearing on how the AUC should be interpreted and used.

In conclusion, we found that one quarter of patients undergoing DC for suspected CAD were rated as inappropriate for the procedure, approximately two thirds of these inappropriate patients had no previous stress test, and ≈90% of inappropriate patients with no prior stress test were asymptomatic with low or intermediate global risk scores.

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**Disclosures**

Potential conflicts of interest are as follows: S. Sharma: Abbott, Angioscore, BSC, DSL/Lilly, and The Medicine Co; S.B. King serves on data monitoring board for Merck & Company, Angioscore, BSC, DSI/Lilly, and The Medicine Co; S.B. King Health (NYSDOH), but the conclusions do not necessarily reflect the opinion of New York State Department of Health. The authors alone are responsible for the content and writing of the paper. The other authors report no conflicts.

**References**


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Edward L. Hannan, Zaza Samadashvili, Kimberly Cozzens, Gary Walford, David R. Holmes, Jr, Alice K. Jacobs, Nicholas J. Stamato, Ferdinand J. Venditti, Samin Sharma and Spencer B. King

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