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Cardiac Imaging

# Impact of an Automated Multimodality Point-of-Order Decision Support Tool on Rates of Appropriate Testing and Clinical Decision Making for Individuals With Suspected Coronary Artery Disease

## A Prospective Multicenter Study

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**Objectives** This study sought to evaluate the impact of a multimodality-appropriate use criteria decision support tool (AUC-DST) on rates of appropriate testing and clinical decision making.

**Background** AUC have been developed to guide utilization of noninvasive imaging for individuals with suspected coronary artery disease (CAD). The effect of a point-of-order AUC-DST on rates of appropriateness and clinical decision making has not been examined.

**Methods** We performed a prospective multicenter cohort study evaluating physicians who ordered CAD imaging tests for consecutive patients insured by 1 large private payer. During an 8-month study period, each study site was granted exemption from prior authorization requirements by radiology benefits managers. An AUC-DST was employed to determine appropriateness ratings for myocardial perfusion scintigraphy (MPS), stress echocardiography (STE), or coronary computed tomographic angiography (CCTA), as well as intended downstream testing and therapy.

**Results** One hundred physicians used the AUC-DST for 472 patients (age 55.6 ± 9.6 years, 61% male, 52% prior known CAD) over 8 months for MPS (72%), STE (24%), and CCTA (5%). The AUC-DST required an average of 137 ± 360 s to determine the appropriateness category that, by American College of Cardiology AUC, was considered appropriate in 241 (51%), uncertain in 96 (20%), inappropriate in 85 (18%), and not addressed in 50 (11%). For tests ordered in the first 2 months compared with the last 2 months, appropriate tests increased from 49% to 61% ($p = 0.02$), whereas inappropriate tests decreased from 22% to 6% ($p < 0.001$). During this period, intended changes in medical therapy increased from 11% to 32% ($p = 0.001$).

**Conclusions** A point-of-order AUC-DST enabled rapid determination of test appropriateness for CAD evaluation and was associated with increased and decreased testing for appropriate and inappropriate indications, respectively. These changes in test ordering were associated with greater intended changes in post-test medical therapy. (J Am Coll Cardiol 2013;62:308–16) © 2013 by the American College of Cardiology Foundation

Noninvasive cardiac imaging exhibits high utility for diagnosis, prognosis, and management of coronary artery disease (CAD) (1). However, its rapid growth and high annual cost to the U.S. healthcare system of $80 billion have triggered concerns of test overuse (2). To address this, the American College of Cardiology (ACC) has developed appropriate

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use criteria (3) for noninvasive imaging, including myocardial perfusion scintigraphy (MPS), stress echocardiography (STE), and coronary computed tomographic angiography (CCTA) (4–6). The application of ACC AUC for MPS, STE, and CCTA has been studied in a variety of single-modality settings, with a non-negligible rate of inappropriate testing reported (7–12). To date, interventions to improve appropriateness of testing have not demonstrated systematic improvement in patterns of performance (11). In lieu of ACC AUC to guide test performance, most private payers employ radiology benefits managers (RBMs) for utilization management who require prior authorization for noninvasive CAD imaging (13). Concerns regarding the clinical and economic value of RBMs have been raised, including vendor variability; lack of transparency of proprietary criteria for authorization of imaging; administrative burden and associated costs; and lack of data to support long-term cost effectiveness (14–16).

In this study, we evaluated the use of an automated, web-based, point-of-order multimodality AUC decision support tool (AUC-DST) in an RBM-free setting for determining rates of appropriateness for noninvasive CAD imaging tests, as well as the impact of the AUC-DST on intended downstream clinical decision making and testing utilization.

## Methods

**Appropriate use criteria decision support tool.** An appropriate use criteria decision support tool (AUC-DST) was developed based upon the most currently available ACC AUC for MPS (2009), STE (2008), and CCTA (2010) at the onset of the study (4–6). The AUC-DST is a web-based application specifically developed for this study (MDDX, San Francisco, California). The user interface was created using a cross-platform compatible language (Flex and ActionScript, Adobe Systems, San Jose, California) with a SQL database backend (Microsoft, Redmond, Washington). Indications for each procedure were extracted from the tables of each AUC document and were manually converted to a stepwise decision tree format before coding into the software program. Pop-up calculators were attached to pertinent indications in the decision tree to assist the user in accurately answering the next step in the decision tree. Calculator types included pre-test likelihood of disease and Framingham Risk Score. All data collected by the tool were stored in a MySQL database (Oracle, Redwood City, California). The application was hosted at Hosting.com (Denver, Colorado). All users were assigned unique logins. Utilization timing, click paths, software-derived AUC rulings, and manual override justifications were recorded along with each user session.

The AUC-DST included all AUC indications specific to CAD evaluation using a tree-and-node algorithm to assign a level of appropriateness of CAD testing by AUC for patients based upon modality type, CAD risk factors, level of pre-test likelihood or risk of CAD, clinical presentation, and specific clinical scenario. Users navigated the AUC-DST to determine the level of appropriateness of a CAD imaging test using a minimal number of "clicks" within a dynamic graphic user interface (Online Fig. 1). When risk estimation was required, the AUC-DST offered optional calculators as recommended by the AUC (17,18). If a specific patient was not addressed by AUC criteria, the AUC-DST generated an appropriateness category of "not addressed." Tests rated by the AUC-DST as non-appropriate (uncertain, inappropriate, or not addressed) resulted in a prompt to the ordering physician, who was then allowed to provide the reason for disagreement with the rating.

**Abbreviations and Acronyms**

**ACC** = American College of Cardiology
**AUC** = appropriate use criteria
**CAD** = coronary artery disease
**CCTA** = coronary computed tomographic angiography
**DST** = decision support tool
**MPS** = myocardial perfusion scintigraphy
**RBM** = radiology benefit manager
**STE** = stress echocardiography

**Study design.** We performed a prospective multicenter cohort study of the AUC-DST to collect AUC ratings for consecutive noninvasive CAD imaging tests covered by a large, single, private payer for non-Medicare individuals (United HealthCare, Minneapolis, Minnesota) from 3 single-specialty cardiology practice sites within 1 large metropolitan area (St. Louis, Missouri) between June 2010 and January 2011. During the study period, the payer allowed participating physicians within the demonstration project who agreed to use the AUC-DST an exemption from RBM prior authorization for noninvasive CAD imaging tests, irrespective of the level of appropriateness determined by the AUC-DST. Physicians prospectively entered CAD risk factors and history at the time of AUC-DST use. CAD risk factors and history were categorized as binary variables, and symptom presentation was classified as typical, atypical, noncardiac, or asymptomatic as previously described (19). Physicians submitted test results and plans for further management after test performance. The study was approved at each of the cardiology practices by their institutional review board.

**Study physicians and patient population.** Physicians and practices were chosen for study participation based upon the following inclusion criteria: 1) employment within 1 of 3 large, single-specialty cardiology practices within 1 large metro area; 2) >500 CAD imaging tests per year per practice; 3) tests ordered were for patients with suspected CAD; 4) tests ordered were for patients who possessed primary coverage by non-Medicare United HealthCare; and 5) agreement by all physicians within the practice to use the AUC-DST in lieu of RBM prior authorization for the entire duration of the study.

Tests ordered by physicians outside of the practice were not included. Similarly, tests ordered for patients with suspected CAD who were covered by payers other than United HealthCare were not included in the present study.

**Test results and proposed follow-up.** After test performance, physicians submitted noninvasive CAD imaging test results and intended downstream management plans to the AUC-DST. Test results were categorized as normal, mildly abnormal, moderately abnormal, or severely abnormal. For MPS and STE, this corresponded to 1% to 5%, 5% to 9.9%, or ≥10% ischemic myocardium or 1, 2 to 3, or >3 myocardial segments exhibiting stress-induced wall motion abnormalities, respectively (20,21). For CCTA, mildly, moderately, and severely abnormal were defined by a maximal per-patient stenosis <50%, 50% to 70%, and ≥70%, respectively (22). For treatment plans, ordering physicians indicated their intention to perform or not perform additional diagnostic testing, inclusive of invasive coronary angiography (with or without intended revascularization) and further noninvasive CAD testing. Ordering physicians also indicated their intention to intensify or not intensify medical therapy independent of further testing.

**Statistical analysis.** Categorical variables are reported as frequencies and percentages, and compared using the Pearson chi-square test or, where there were cell counts <6, the Fisher exact test. Continuous variables are reported as means and standard deviations, and compared using the 2-sample Student *t* test or Wilcoxon rank sum test, as appropriate. For comparisons with more than 2 categories, if significant associations were found, additional exploratory chi-square tests were conducted for all pairwise comparisons at each level using a Bonferroni-adjusted p value, and salient results were reported. The Cochran-Armitage test for trend and Cuzick test for trend were used to compare categorical and continuous variables across temporally ordered groups, respectively. We estimated that in order to detect a relative decrease of 20% in inappropriate testing with 80% power, this study would require 120 patients in each group between the first and last observation period. A 2-sided $p < 0.05$ was considered statistically significant. All analyses were performed with SAS (version 9.2, SAS Institute, Cary, North Carolina). F.Y.L. and J.K.M. were solely responsible for the design and conduct of the study, had full access to all the data in the study, and take responsibility for the integrity of the data and the accuracy of the data analysis and manuscript.

## Results

**Baseline characteristics and ordering patterns.** At 3 single-specialty cardiology practices, 100 physicians utilized the AUC-DST for 8 months and 472 patients (age 55.6 ± 9.6 years, 61% male, 52% prior CAD). Physicians ordered testing for patients most frequently for MPS (n = 338, 72%), followed by STE (n = 111, 24%) and then CCTA (n = 23, 5%). Among the 100 participating physicians, 94 ordered ≥1 MPS, 38 ordered ≥1 STE, and 8 ordered ≥1 CCTA. Patients for whom MPS was ordered were significantly older, had a higher burden of CAD risk factors, and had a higher prevalence of prior known CAD when compared with patients for whom STE or CCTA was ordered (Table 1).

**AUC-DST use, clinical scenarios, and level of appropriateness.** The distribution of AUC-DST use by most common clinical scenarios and levels of appropriateness are shown in Table 2. The chi-square or Fisher exact p values represent the 2 × 3 comparisons of each level versus the other levels combined. The AUC-DST required 137 ± 360 s from the time of the initial modality selection to reach a recommendation of appropriateness category. Level of appropriateness required <60 s for 247 (52%) test cases. The most common AUC categories used were "Symptomatic detection of CAD" (37%), followed by "Asymptomatic detection of CAD" (26%), and "Prior revascularization (26%)." Bonferroni-adjusted pairwise comparisons (3 for each statistically significant level) showed that for "Asymptomatic detection of CAD," "Symptomatic detection of CAD," "Prior testing," and "Other," the CCTA group was significantly different from the STE test group, and in the case of "Asymptomatic detection of CAD" and "Other," was also significantly different from the MPS group. By the AUC-DST, 51% of the 472 tests were appropriate, 20% were uncertain, 18% were inappropriate, and 11% were not addressed by AUC. Pairwise comparisons here showed that

**Table 1 Baseline Characteristics**

| Clinical Characteristic | Overall (N = 472) | MPS (n = 338) | STE (n = 111) | CCTA (n = 23) | p Value* |
|---|---|---|---|---|---|
| Age, yrs | 55.6 (9.6) | 57.3 (8.0) | 51.4 (11.6) | 50.3 (12.8) | <0.0001 |
| Male | 287 (61%) | 222 (66%) | 51 (46%) | 14 (61%) | 0.0011 |
| Hyperlipidemia | 328 (69%) | 258 (76%) | 58 (52%) | 12 (52%) | <0.0001 |
| Diabetes | 98 (21%) | 86 (25%) | 12 (11%) | 0 (0%) | 0.0002 |
| Hypertension | 316 (67%) | 258 (76%) | 49 (44%) | 9 (39%) | <0.0001 |
| Family history of CAD | 235 (50%) | 183 (54%) | 49 (44%) | 3 (13%) | 0.0003 |
| Smoker | 170 (36%) | 130 (38%) | 37 (33%) | 3 (13%) | 0.04 |
| Peripheral artery disease | 24 (5%) | 22 (7%) | 2 (2%) | 0 (0%) | 0.08 |
| Prior known CAD | 191 (40%) | 165 (49%) | 24 (22%) | 2 (9%) | <0.0001 |
| Post-menopausal (among women) | 74 (40%) | 50 (15%) | 20 (18%) | 4 (17%) | 0.22 |

*Fisher exact test applied to comparisons involving cell counts <6.
CAD = coronary artery disease; CCTA = cardiac computed tomographic angiography; MPS = myocardial perfusion single-photon emission computed tomography; STE = stress echocardiography.

**Table 2** Differences in Indications and Appropriateness Among Modalities

| Clinical Classification of Indication/AUC-DST Node | Overall | MPS | STE | CCTA | p Value* |
|---|---|---|---|---|---|
| Asymptomatic (detection of CAD) | 125 (26) | 90 (27) | 35 (32) | 0 (0) | 0.002 |
| Symptomatic (detection of CAD) | 173 (37) | 107 (32) | 60 (54) | 6 (26) | <0.001 |
| Past revascularization | 121 (26) | 105 (31) | 11 (10) | 5 (22) | <0.001 |
| Acute coronary syndrome | 9 (2) | 8 (2) | 1 (1) | 0 (0) | 0.66 |
| Pre-operative evaluation | 16 (3) | 14 (4) | 2 (2) | 0 (0) | 0.49 |
| Prior test results | 16 (3) | 12 (4) | 1 (1) | 3 (13) | 0.02 |
| Other | 12 (3) | 2 (1) | 1 (1) | 9 (39) | <0.001 |
| Appropriateness rating | | | | | |
| Appropriate | 241 (51) | 178 (53) | 50 (45) | 13 (57) | 0.33 |
| Uncertain | 96 (20) | 90 (27) | 2 (2) | 4 (17) | <0.001 |
| Inappropriate | 85 (18) | 44 (13) | 40 (36) | 1 (4) | <0.001 |
| Not addressed | 50 (11) | 26 (8) | 19 (17) | 5 (22) | 0.004 |

Values are n (%). *Fisher exact test applied to comparisons involving cell counts <6. *Global chi-square with 12 degrees of freedom = 173.4; p value <0.001. **Global chi-square with 6 degrees of freedom = 63.4; p value <0.001.

AUC = appropriate use criteria; DST = decision support tool; other abbreviations as in Table 1.

the STE group was significantly different from both the MPS and CCTA tests for uncertain or inappropriate tests.

Among all tests ordered, the 3 most common clinical indications used were for MPS, reflecting the greater use of MPS, and comprised 26% of all studies (Table 3). The most common appropriate clinical indication for which any CAD imaging test was ordered was for "Detection of CAD in symptomatic patient with intermediate pre-test probability of CAD, ECG interpretable, and able to exercise" by MPS (10% of all studies), whereas the most common uncertain indication was "Risk assessment post-revascularization in asymptomatic patient ≥2 years post-PCI" by MPS (7% of all studies), whereas the most common inappropriate indication was for "Detection of CAD in asymptomatic patient with low CHD risk (Framingham risk criteria)" by STE (4% of all studies). More than half of the studies considered inappropriate (56% of all studies) were for clinical scenarios addressing 3 low-risk patient types, including: 1) detection of CAD in asymptomatic patients with low CHD risk (MPS) (n = 21); 2) detection of CAD in asymptomatic patients with low CHD risk (STE) (n = 18); and 3) detection of CAD in symptomatic patients with low pre-test probability of CAD and able to exercise (STE) (n = 9).

Ordered MPS, STE, and CCTA did not differ significantly with respect to the frequency of studies categorized as appropriate (p = 0.33). MPS tests ordered were more likely to be considered uncertain compared with STE or CCTA (27% for MPS vs. 2% for STE and 17% for CCTA; p < 0.01). STE tests ordered were most likely to be considered inappropriate (36% for STE vs. 13% for MPS and 4% for CCTA, p < 0.01), whereas CCTA tests ordered were most likely to be not addressed (8% for MPS vs. 17% for STE and 22% for CCTA, p = 0.004).

**Physician disagreement with AUC-DST.** For studies considered nonappropriate, physicians provided their rationale for test ordering for 48 (21%) of cases. Among these, physicians considered the AUC incorrect for 35%, and estimated the pre-test likelihood or risk of patients higher

**Table 3** Most Common Indications by Modality and Appropriateness Rating

| Modality | n (%)* | Description | Appropriateness |
|---|---|---|---|
| MPS (n = 338) | 49 (10) | Detection of CAD in symptomatic patient with intermediate pre-test probability of CAD, ECG interpretable, and able to exercise | A |
| | 40 (8) | Risk assessment post-revascularization in symptomatic patient | A |
| | 35 (7) | Risk assessment post-revascularization in asymptomatic patient ≥2 years post-PCI | U |
| STE (n = 111) | 20 (4) | Detection of CAD in symptomatic patient with intermediate pre-test probability of CAD, ECG interpretable, and able to exercise | A |
| | 18 (4) | Detection of CAD in asymptomatic patient with low CHD risk (Framingham risk criteria) | I |
| | 14 (3) | Detection of CAD in acute chest pain with intermediate pre-test probability of CAD, no dynamic ST-segment changes, and negative cardiac enzymes | A |
| CCTA (n = 23) | 5 (1) | Evaluation of pulmonary vein anatomy prior to invasive radiofrequency ablation for atrial fibrillation | A |
| | 3 (0.6) | Detection of CAD in symptomatic patient with intermediate pretest probability of CAD, ECG interpretable, and able to exercise | U |
| | 3 (0.6) | Evaluation of suspected coronary artery anomalies | A |

*As a percentage of all 427 tests.

A = appropriate; CHD = coronary heart disease; ECG = electrocardiogram; I = inappropriate; PCI = percutaneous coronary intervention; U = uncertain; other abbreviations as in Table 1.

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than the AUC for 48%. For 17% of nonappropriate cases, physicians felt that their specific patient did not fit ideally into the clinical scenario described by the AUC-DST.

**Test findings and intended downstream treatment plan.** Of 472 tests, it was reported that physicians did not have available results or further plans for testing in 22 (4.7%). From the remaining 450 examinations, 48% were reported as abnormal. Among test types, CCTA was most likely to be abnormal (50%), followed by MPS (47%) and STE (10%) ($p < 0.01$). Studies rated uncertain (56%) were most likely to be abnormal, followed by appropriate (37%), not addressed (30%), and inappropriate (28%, $p < 0.01$). Nonappropriate studies were no more or less likely to be abnormal than appropriate studies (Table 4).

Overall, physicians planned no further testing for 76% patients, but intended to intensify medical therapy for 25% patients. For normal tests, physicians were more likely to do no further testing than for abnormal tests (99% vs. 41%, $p < 0.01$) and less likely to intensify medical therapy (15% vs. 40%; $p < 0.01$). There was no difference in plans for further testing by level of appropriateness (80% for appropriate, 69% for uncertain, 76% for inappropriate, 79% for not addressed; $p = 0.23$). Physicians were less likely to plan medical therapy changes for patients whose testing was inappropriate (28% for appropriate, 33% for uncertain, 9% for inappropriate, and 21% for not addressed; $p = 0.001$).

**Changes in tests and test results after use of the AUC-DST.** There was no significant trend in the duration required to complete the DST over the 4 observation periods, nor were changes observed for patient age, number of CAD risk factors, or frequency of prior CAD over time (test for trend $p > 0.05$ for all).

Across the 8-month study period, the frequency of tests considered appropriate by the ACC AUC increased, with a corresponding decline in the frequency of tests considered inappropriate ($p < 0.05$ for both) (Fig. 1). The frequency of inappropriate testing decreased from 22% in the first 2-month period to 6% in the last 2-month period ($p = 0.0001$), and appropriate studies increased from 49% in the first 2-month period to 61% in the last 2-month period ($p = 0.02$). Pertaining the MPS, the test type that comprised nearly three-fourths of tests ordered, a significant reduction in test ordering occurred for indications considered inappropriate by ACC AUC between the first and last quarter (17% vs. 2%, $p = 0.002$), with an accompanying trend towards increased rates of appropriateness (49% vs. 62%, $p = 0.15$).

The percentage of studies reported as normal or abnormal did not change over time (Fig. 2). No significant differences were noted in the frequency of planned further testing across the study period ($p = 0.30$) (Fig. 3, blue bars). Plans for medical therapy changes irrespective of further testing increased from 11% to 32% from the first 2 to the last 2 months, ($p = 0.001$) (Fig. 3, red bars).

## Discussion

In this prospective, multicenter, observational cohort study, we demonstrated that a web-based DST for AUC for noninvasive CAD imaging to guide test ordering could be effectively employed for an array of testing types and as a potential alternative to RBMs. Use of the AUC-DST was associated with increases in appropriate testing and decreases in inappropriate testing over an 8-month period. This AUC-DST

**Table 4** Likelihood of an Abnormal Result by Appropriateness Among the Most Common Indication Groups for Testing

| Indication | Appropriate | Uncertain | Inappropriate | Not Addressed | p Value |
|---|---|---|---|---|---|
| Asymptomatic (detection of CAD) | | | | | |
| Overall | 2/15 (13) | 18/40 (45) | 11/47 (23) | 6/18 (33) | 0.07 |
| MPS | 2/13 (15) | 17/39 (53) | 7/21 (33) | 6/14 (43) | 0.30 |
| STE | 0/2 (0) | 1/1 (100) | 4/26 (15) | 0/4 (0) | 0.08 |
| CCTA | 0/0 (N/A) | 0/0 (N/A) | 0/0 (N/A) | 0/0 (N/A) | N/A |
| Symptomatic (detection of CAD) | | | | | |
| Overall | 37/128 (29) | 0/5 (0) | 2/17 (12) | 4/16 (25) | 0.25 |
| MPS | 33/87 (38) | 0/1 (0) | 2/8 (25) | 2/7 (29) | 0.73 |
| STE | 4/41 (10) | 0/1 (0) | 0/9 (0) | 2/9 (22) | 0.46 |
| CCTA | 0/0 (N/A) | 0/3 (0) | 0/0 (N/A) | 0/0 (N/A) | N/A |
| Prior revascularization | | | | | |
| Overall | 29/55 (53) | 33/46 (72) | 4/8 (50) | 1/5 (20) | 0.06 |
| MPS | 28/49 (57) | 32/45 (71) | 3/5 (60) | 0/0 (N/A) | 0.37 |
| STE | 0/4 (0) | 0/0 (N/A) | 0/2 (0) | 0/4 (0) | N/A |
| CCTA | 1/2 (50) | 1/1 (100) | 1/1 (100) | 1/1 (100) | 0.60 |
| All other indications | | | | | |
| Overall | 18/35 (51) | 0/0 (N/A) | 5/7 (71) | 3/8 (38) | 0.42 |
| MPS | 14/24 (58) | 0/0 (N/A) | 5/6 (83) | 2/5 (40) | 0.33 |
| STE | 0/2 (0) | 0/0 (N/A) | 0/1 (0) | 0/2 (0) | N/A |
| CCTA | 4/9 (44) | 0/0 (N/A) | 0/0 (N/A*) | 1/1 (100) | 0.29 |

Values are n abnormal/n total (%). N/A indicates that the total per cell = 0 or insufficient n to allow for comparison.
Abbreviations as in Table 1.

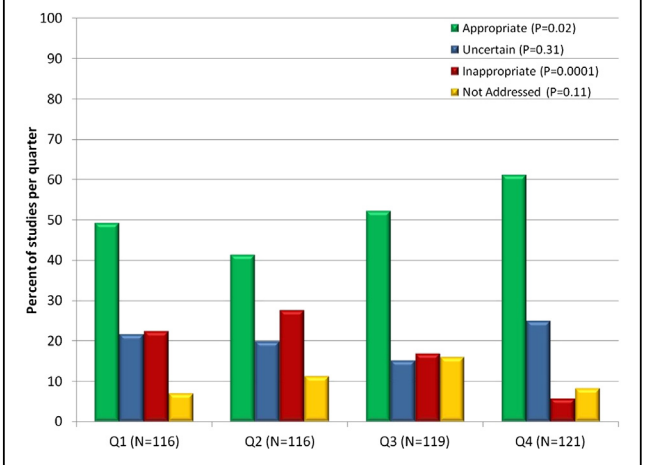


**Figure 1** **Changes in the Percentage of Studies at Each Level of Appropriateness Using the AUC-DST From Q1 to Q4 of the Intervention**

Appropriate studies increased in proportion whereas inappropriate studies decreased. Quarter 1 (Q1) was the first 2-month period, and Q4 was the last 2-month period. Global chi-square with 9 degrees of freedom = 30.2; p value <0.001. AUC-DST = appropriate use criteria decision support tool.

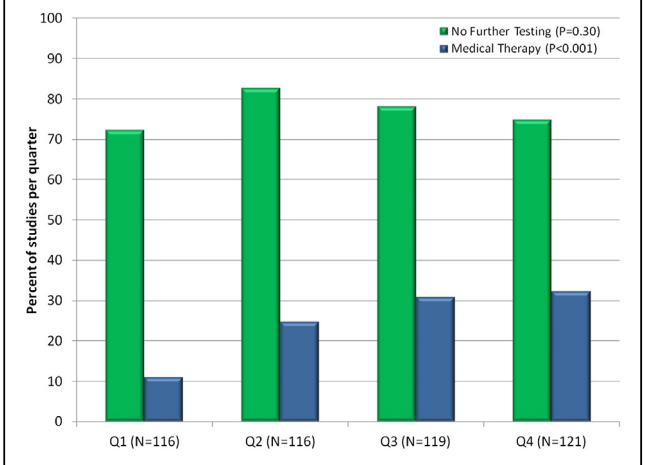


**Figure 3** **Changes in Physician Treatment Plans Over Time**

Planned medical therapy was defined as maintenance or increase of medication for coronary artery disease, without specific details on therapy, irrespective of plans for testing. There was no change in plans for downstream testing over time, whereas physician plans for medical therapy increased from quarter 1 (Q1) to Q4.

required an average of approximately 2 min for a physician to determine the category of appropriateness, as regarded by the ACC AUC. Further, the AUC-DST was deployed at the point of order, thus providing physicians with instant communication regarding appropriateness of testing. Given the immediacy of feedback, the AUC-DST offered an educational component as well, which may have been associated with the observed trends toward increased intended changes in medical therapy changes without affecting intended rates of downstream testing. To our knowledge, this study is the first to evaluate the use of an AUC-DST to describe behavior of physician-preferred over policy-based testing, as well as the first to relate levels of appropriateness across multiple CAD imaging modalities to test results and future intended treatment plans. Given the large number of participating physicians from multiple community-based cardiology practices, these results should be considered widely generalizable and reflective of common clinical practice.

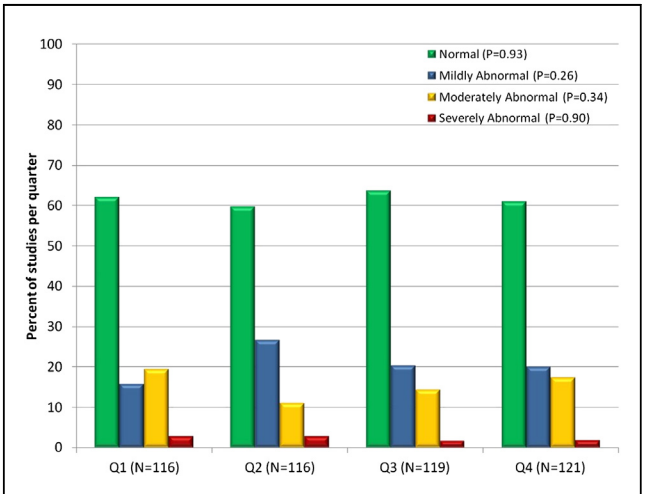


**Figure 2** **Changes in the Percentage of Studies With Normal and Mildly, Moderately, or Severely Abnormal Results**

Severity of abnormalities did not change over the time of the intervention. Global chi-square with 9 degrees of freedom = 6.7; p value = 0.67. Q = quarter.

To our knowledge, this study is also the first prospective evaluation of an AUC-based DST in an unaffected environment wherein physicians could perform any test, irrespective of appropriateness, without restrictions from RBM prior authorization requirements. Notably, the physician-preferred test ordering patterns enabled by the AUC-DST was associated with an overall 18% rate of inappropriate tests ordered, which is in keeping with the 15% to 20% of RBM denials for prior authorization requests for advanced imaging tests. As a potential advantage over RBMs, the AUC-DST served as a continuous, immediate, educational feedback mechanism to ordering physicians. We observed a >20% increase and >75% decrease in rates of appropriate and inappropriate testing, respectively, between the first and last quarters of the 8-month study. Across quarters, rates of inappropriate tests ordered dropped from 22% to 6%. The findings suggest that the AUC-DST may be an effective alternative to policy-based prior authorization requirements imposed by the RBM process, and may represent a method for curbing inappropriate imaging with lesser administrative burden, enhancing transparency of test authorization criteria, improving test ordering in accordance with published AUC documents, and serving as a continuous educational feedback mechanism to ordering cardiologists. Direct comparative studies of the AUC-DST versus RBMs for test appropriateness,

as well as evaluation of the effects of the AUC-DST for noncardiologists, are now warranted. Further, because this study did not evaluate the clinical and/or economic outcomes of the AUC-DST against the standard of care method, these studies are also now necessary.

Our study results differ from prior studies of cardiac imaging test appropriateness. In a single-modality investigation of MPS, Hendel et al. (11) observed no impact on the frequency of appropriate, uncertain, or inappropriate MPS following educational interventions that included optional "on-demand reporting," summary reports, blinded comparison of test performance versus other clinical sites, sample letters for distribution, and pocket cards. These results are in accordance with those observed by Gibbons et al. (23) and Willens et al. (24) for MPS and stress echocardiography, respectively, wherein educational efforts such as grand rounds and other presentations, newsletters, and meetings with physician administrators were ineffective at reducing test inappropriateness. By contrast, Chinnaiyan et al. (25) performed a continuous quality improvement initiative for coronary CT angiography in a statewide multicenter registry, and observed reductions in inappropriate testing and increases in appropriate testing when education was provided to physicians in the context of losing coverage for CT.

The present study differs from each of these prior investigations in that patient- and scenario-specific educational feedback was provided necessarily as a function of using the AUC-DST in a manner that promoted learning and quality improvement through "hands-on" usage rather than formal didactics; continuously as opposed to sporadically; from a multimodality rather than single-modality perspective; and as a method for avoidance of time-consuming RBM processes. Further, the AUC-DST used in the present study communicated feedback at an earlier stage in the CAD evaluation process—that is, at the time of test ordering—when alternative tests may be easily selected without communication delays that would occur later in a point-of-service model within an imaging lab or even later at occasional quality improvement meetings. It seems probable that affecting change in ordering patterns must, in fact, be done at the point of order rather than point of service. In addition, it appears effective if feedback is provided directly to the ordering cardiologist provider over administrative or ancillary staff that may have less familiarity with patient presentation or AUC, as was performed in our study.

Further, we identified differences between test type and appropriateness categories. Although no differences in appropriateness were identified for MPS, STE, and CCTA, MPS test ordering was more likely to be uncertain, STE more likely to be inappropriate, and CCTA likely to be not addressed. These findings may have occurred for a myriad of reasons, including familiarity with the advantages and limitations of the test type as well as the patient-specific level of pre-test likelihood of CAD. Patterns were also observed for specific clinical scenarios for level of appropriateness, with 3 indications most commonly appropriate, 1 indication for uncertain, and 3 indications for inappropriate found to be most common. These findings suggest that educational intervention for inappropriate studies may be achievable by education for a small number of scenarios.

An important criticism of AUC has been their lack of validation against outcomes (26). We observed a nonlinear relationship between increasing appropriateness and test normalcy, likely reflecting the complexity and diversity of AUC indications. However, even within strata of asymptomatic patients, we observed >10% abnormal test results among inappropriate indications, similar to prior observations for rest transthoracic echocardiography (12,27). In this regard, our study findings are not inconsistent with prior studies. This imperfect negative predictive value may be partially explained by the nonuniform uptake of AUC in cardiology practice, as well as the possibility that the likelihood of abnormality of a certain test does not necessarily dictate its level of appropriateness. A simple exemplary scenario is that of an asymptomatic patient with a prior myocardial infarction who undergoes coronary artery bypass surgery and subsequent nuclear single-photon emission computed tomography imaging 6 months after surgery. Although the perfusion deficits associated with the prior infarct will be observed by single-photon emission computed tomography (thereby rendering the test "abnormal"), this application is neither clinically valuable nor endorsed by the ACC AUC. Importantly, the negative predictive value of proprietary RBM guidelines is unknown. We also observed no differences in intended downstream testing rates by level of appropriateness, but a lower likelihood of medical therapy changes for inappropriate testing. Thus, the decreasing number of inappropriate studies over the course of the intervention may have contributed to the increase in medical therapy over time. It is noteworthy to mention that this study did not address the issue of downstream test "layering" or CAD event utilization, such as for death, myocardial infarction, or CAD-related hospitalization. The findings have been evaluated by prior studies such as the SPARC (Study of Myocardial Perfusion and Coronary Anatomy Imaging Roles in Coronary Artery Disease) registry; however, these studies have lacked information related to test appropriateness (28).

To combat overuse or misuse of imaging, more than 90% of the largest private payers have contracted with RBMs who require prior authorization of imaging as a front-end safeguard to managing resources, a method that has demonstrated success at reducing costs (13). Yet RBM requirements for prior authorization have drawn objections from practitioners and physician specialty societies, with contentions that such proprietary approaches are not consistently rooted in scientific evidence or published AUC; differ across or within geographical regions; and are not uniformly transparent (15). Critics of RBMs further contend that incentives to reduce costs in a for-profit environment may result in indiscriminate reduction of medically necessary imaging, unnecessary delays in healthcare delivery, and worsened healthcare quality. By contrast, ACC AUC are developed by a 2-step RAND method by a panel of experts and

non-experts who consider the totality of scientific evidence to date. Further, no uniform method exists for obtaining prior authorization across the multitude of RBMs, and additional administrative resources are thus required, with $7,500 per cardiologist per year estimated as necessary to accommodate RBM requirements (14). Indeed, prior decision models suggest that RBMs simply shift costs toward physician practices, with an unknown impact on overall societal healthcare costs (29).

Our study may be directly relevant to policymakers who must balance the distribution of healthcare resources, with noninvasive cardiac imaging highly consumptive and thus, a high priority. Between 2000 and 2006, per-person imaging costs in the United States experienced an almost 2-fold rate of growth, which was twice as high as for other services to Medicare beneficiaries and far in excess of growth in CAD prevalence (13,30–32). Whether use of RBMs produces salutary healthcare and economic outcomes has been a subject of great debate, having been addressed in the recent Medicare Improvement and Patient Protection Act, Congressional budget proposals, the American Medical Association report to Congress, and the ongoing Medicare Imaging Demonstration project (33–35). The results of our study suggest that a computerized point-of-order decision support system can reliably track physician behavior and that favorable changes can occur, even in the absence of RBM prior authorization requirements. Our results engender promise of the value of such an AUC-DST for improving appropriate testing, enhancing transparency, and reducing administrative burden. At the same time, our study highlights challenges in directly linking process measures to clinical outcomes.

Finally, the present study evaluated the test ordering patterns solely for cardiologists, rather than noncardiologists that include primary care physicians, emergency department physicians, and other noncardiology specialists. Importantly, prior studies, including that performed by Hendel et al. (11), have demonstrated that rates of inappropriate test ordering are higher in noncardiologists compared with cardiologists. It seems feasible that the AUC-DST may have had a more dramatic effect in test appropriateness had this study included them.

**Study limitations.** First, although participating physicians were exempt from prior authorization requirements during the study, no direct comparison to RBMs was performed. Thus, although we observed improvements in rates of appropriate testing and reductions in rates of inappropriate testing, the direct comparison of an AUC-DST versus RBMs for test appropriateness rates, costs, and clinical outcomes now appears warranted. Second, we tested the impact of an AUC-DST alone without the confounding influence of payer-designated RBMs. In doing so, our study was restricted to tests ordered for individuals with primary payer coverage with a waiver of RBM pre-authorization, which was offered only for non-Medicare private payer–covered individuals. As such, the generalizability of our study results to individuals covered under other private or public payers should be done with caution. In addition, because the payer only allowed the RBM waiver as an alternative cost-containment strategy, a control group without either an RBM or AUC-DST was not available for comparison. In this regard, it is possible a Hawthorne effect may have applied, that is, simply informing providers that their appropriateness would be observed and evaluated may have been an intervention in itself. This effect, however, has not been observed in prior studies such as that of Hendel et al. (11). Third, we studied only the impact of the AUC-DST for board-certified cardiologists, and whether our results can be applied to primary care physicians or other physician specialists cannot be definitively determined. Because noncardiologists order approximately half of the noninvasive tests for CAD, this is an important area of further study (36). Fourth, as the AUC-DST follows the ACC AUC criteria, it did not offer or compare alternative tests for the same indication. More recent guidelines with uniform indication definitions across modalities may be more useful for intermodality comparison. The anticipated multimodality ACC AUC, whose publication is expected later this year, may provide a more integrated guidance document for futures studies. Finally, we ascertained test results and intended changes in therapy, but lacked information related to long-term health and economic outcomes.

## Conclusions

An automated point-of-order AUC-DST successfully addressed most tests ordered for CAD evaluation, with rapid provision of test-specific appropriateness. Use of the AUC-DST was associated with an increase in appropriate testing and a decrease in inappropriate testing. A point-of-order AUC-DST may be a transparent, efficient, and educational mechanism to guide imaging utilization for individuals with suspected CAD.

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**Key Words:** appropriate use criteria ■ cardiac computed tomographic angiography ■ decision support tool ■ myocardial perfusion SPECT ■ stress echocardiography.

## APPENDIX

**For a supplemental figure, please see the online version of this article.**