Advances in coronary computed tomography angiography (CTA) have made it possible to image the coronary vasculature noninvasively, with excellent accuracy for defining the presence and severity of luminal stenoses, especially in low-to-intermediate risk individuals.1–3 In addition, it has been shown to identify individuals at risk for all-cause mortality.4 This suggests that coronary CTA may be used to exclude coronary artery disease in a substantial proportion of appropriately selected patients, thus allowing scarce healthcare resources to be focused on those patients truly requiring long-term medical therapy and expensive invasive procedures. However, exposure to ionizing radiation is a significant limitation of this technology.5–8 Substantial cumulative doses because of repeated testing is concerning for increased lifetime attributable risk of cancer.9,10 However, radiation dose from coronary CTA can be substantially reduced with specific scanner hardware acquisition protocols.8,11 We have reported previously the feasibility of significant dose reduction in the Advanced Cardiovascular Imaging Consortium (ACIC) with intensive education and implementation of a best-practice algorithm, during the first study period, during which there was a 53.3% decrease in median dose after intervention.12

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The objectives of the present study were to determine whether these reduced doses would be sustained during long-term follow-up, and if advancing CT technology and continued educational interventions would lead to progressive dose reduction over time.
Methods

Study Population and Setting

The ACIC is a collaborative coronary CTA quality improvement initiative sponsored by the Blue Cross Blue Shield/Blue Care Network of Michigan and currently includes 43 hospitals and outpatient imaging centers. The sites range in type from large academic centers, community hospitals, and free-standing imaging centers. Data collection for ACIC is approved by institutional review boards at participating centers and includes a waiver of consent. At its inception in July 2007, 15 participating hospitals began collecting radiation data; only those sites are included in this study. The details of these sites are presented in Appendix I in the online-only Data Supplement.

Study Design

At the original 15 sites, a 53% reduction in median radiation dose was observed from the inception of ACIC (July to August 2007) from median dose-length product (DLP) of 1493 (interquartile range [IQR], 855–1823) to 697 (IQR, 407–1163) mGy-cm during a period of 1 year (P<0.0001).12

The end period of the previous study (May to June 2008) formed the control period of the present study. The follow-up I (July 2008 to June 2009) period was selected prospectively to examine the effect of continued educational efforts on radiation dose. Follow-up II (July 2009 to April 2011) was selected retrospectively after collection of data was complete, on the basis of beginning of data collection after all sites had adopted newer scanner technology.

During follow-up I, the dose-reduction Collaborative Quality Initiative (CQI) program was maintained using the previously established best-practice algorithm (Table 1). The radiation dose at each site was monitored and comparative data were reported to each site. Dose reduction strategies were encouraged via regular ACIC meetings and periodic feedback to sites via personal communication with site physicians and technologists. In addition, implementation of newly available scanning techniques was promoted. To this end, data on adoption and implementation of newer technologies were monitored and reported as described above. Advanced scan protocols in the use during this period included prospective ECG-triggered scans, fast-pitch spiral scans, and wide-detector array acquisitions. Across the consortium, the target median dose was set at 10 mSv.

Registry Data

As previously reported,11 detailed data collected for the ACIC include information about patient characteristics, indications, and imaging protocols. These are obtained from structured patient interviews, medical records, and point-of-care medical and scan information. A technologist information sheet includes the scanner manufacturer and model, protocol parameters, including longitudinal scan range (cm), scan duration (seconds), scan voltage in peak kilovolts (kVp), the use of ECG-gated tube current modulation, resulting radiation measurements, and calculated doses, including CT dose index-volume, DLP, and calculated effective dose in milliSieverts (mSv). Importantly, the study data analysis included the total radiation dose from all parts of the coronary CTA scan, including topogram, test bolus or monitoring scan, coronary angiography, and calcium score, if performed. This reporting of total dose is distinct from some studies of radiation dose at each site were reviewed by the consortium program director and sites with at least quarterly, and sites with otherwise, medians and 25th, 75th percentiles (IQR) are given. Anderson–Darling tests were applied to check for normality. Age

Estimation of Radiation Dose

Radiation doses were estimated by previously described methods.14–18 Each scanner provides a protocol summary containing the DLP (in mGy-cm) for each image series, which integrates estimated absorbed radiation in the x, y, and z directions based on the CT dose index-volume. The effective radiation dose was derived from the summed DLP multiplied by the European Working Group for Guidelines on Quality Criteria in Computed Tomography conversion coefficient (k=0.014 mSv/mGy-cm).19

Image Quality Assessment

On the ACIC data collection forms, physicians rate the quality of each study on a per-patient basis according to the following scale:

1. Excellent: Complete absence of motion artifacts, excellent signal:noise ratio, and clear delineation of vessel walls, with the ability to assess luminal stenosis and plaque characteristics.
2. Good: Nonlimiting motion artifacts, reduced signal: noise ratio, and calcifications are present, with preserved ability to assess luminal stenosis and plaque characteristics.
3. Adequate: Reduced image quality because of any combination of noise, motion, poor contrast enhancement, or calcium that significantly impairs ease of interpretation. Image quality sufficient to rule out significant stenosis.

Best-Practice Algorithm for Dose Reduction

As previously reported, a best-practice algorithm was created for radiation dose reduction (Table 1). This model was based on previously published methods of radiation dose reduction and included minimizing longitudinal scan range, the use of sufficient β-blocker doses to control heart rate and heart rate variability, maximizing use of ECG-gated tube current modulation, narrowing the acquisition window at low, stable heart rates, and decreasing scan voltage in normal weight individuals.12 During follow-up II, these recommendations were further modified to encourage the use of prospective gating and newer technologies such as high-pitch helical scanning along with reiteration of patient-specific scanning protocols specified earlier. At every quarterly consortium meeting, specific lectures on latest scanner technology, patient preparation, and customization of protocols to patient characteristics were provided. During follow-up II, the educational component included emphasis on adoption of newer techniques, particularly prospective gating. Ongoing consultations with representatives of scanner manufacturers and the lead technologist for the consortium were arranged for individualized on-site instruction in scanner-specific techniques. As part of the radiation dose reduction program, acquisition of coronary artery calcium scores was recommended only if specifically ordered by the referring physician. At the end of every quarter, each site received feedback on their dose, site-specific trends, and comparison with the consortium as a whole. Radiation doses at each site were reviewed by the consortium program director and sites with at least quarterly, and sites with median doses considered out of range of the target dose of 10 mSv were contacted to discuss remediation.

Statistical Analyses

The primary end point of radiation dose (in DLP) was examined between the time periods using Wilcoxon rank-sum tests. The image quality was examined between the time periods using Pearson’s χ² tests. Missing data remained missing. There were no substitutions or interpolations to replace the missing data. Continuous variables are shown as mean±SD where applicable, otherwise, medians and 25th, 75th percentiles (IQR) are given.
was examined using a Student *t* test, whereas body mass index (BMI), heart rate, and the remaining continuous variables were examined using nonparametric Wilcoxon rank-sum tests as they were not normally distributed. Categorical variables were examined using 2-sided *χ*<sup>2</sup> tests and are shown as counts and percentage frequency. All *P* values were 2 tailed.

To assess the influence separately of various factors in predicting a target dose of ≤10 mSv in follow-up II among patients undergoing retrospectively or prospectively gated coronary CTA, several logistic regression multivariable analyses were performed, including (1) all patients, (2) all patients undergoing nonretrospective gating, and (3) all patients undergoing prospective gating. Included were the
variables that are part of the best-practice algorithm (Table 1) along with sex, age, and high volume. All models were checked for confounding and multicollinearity using interaction terms and examining various subsets of scans. Some variables were removed because of the colinearity and were the reason for separate models for retrospective and nonretrospective gating. In addition, median radiation doses were examined within each scanner type for subsets of data to determine dose differences among scanner manufacturers and types. Data analyses were performed using SAS for Windows, version 9.2, Cary, NC. The median radiation doses were examined within each scanner type for subsets of data.

Results
Clinical Characteristics Study Group
During the entire study period from May 1, 2008, through April 30, 2011, 11 901 patients underwent coronary CTA scanning at the included study sites (Table 2). Patient characteristics remained consistent throughout the study period with 2 exceptions. An initial trend of decrease in referral rates for dyspnea and concomitant coronary artery calcium was observed in follow-up I, and this reversed over time. There was an increase in full thorax scans during the follow-up II, constituting bypass graft evaluation and triple rule-out (combined coronary and aorta or pulmonary artery angiography) scans. Examining the trend across the time periods, there was an overall decrease in family history of premature coronary artery disease and increase in prior coronary artery disease, dyspnea, full thorax, and triple rule-out scans over time, presumably reflective of emerging data on clinical use of CTA during the study period.

Newer Dose-Reduction Methods
During follow-up I, high-pitch helical CT scanner was introduced at 1 site, adaptive statistical iterative reconstruction at 3 sites, and volumetric 320-slice CT at 1 site. In addition, 6 of the remaining 10 sites adopted prospective gating.

A listing of the CT-scanner manufacturer, model, and accompanying median radiation doses is presented in the Appendix I in the online-only Data Supplement.

Primary Study End Point (Radiation Dose)

Control Versus Follow-Up I
During this period, no significant change in radiation dose was noted 697 (IQR, 407–1163) to 675 (IQR, 418–1146) mGy-cm and 10 (IQR, 6–16) to 9.5 (IQR, 5.9–16) mSv (P=0.93). There was a significant increase in nonretrospective gating during this time period.

Follow-Up I Versus Follow-Up II
An incremental 31% dose reduction was noted after introduction of newer scanner technology in follow-up II period at 468 (IQR, 292–811) mGy-cm and 6.6 (IQR, 4.1–11.4) mSv compared with follow-up I (P<0.0001). There was an increase in the use of β-blockers (75%–82%; P<0.0001). At the end of the study and during the final bimonthly period, the median DLP was 350 mGy-cm or 4.9 mSv, representing a 51% dose reduction compared with the control period (Figure).

Examining trends across the study period, there was an overall decrease in scan length and increase in the use of β-blockers (P<0.0001; Table 3).

Secondary Study End Point (Image Quality)

Control Versus Follow-Up I
There was no difference in the percentage of diagnostic-quality scans (92% versus 94; P=0.85).

Table 2. Patient Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control (n=835)</th>
<th>Follow-up I (n=4489)</th>
<th>P-value*</th>
<th>Follow-up II (n=6577)</th>
<th>P-value†</th>
<th>P-value‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean±SD)</td>
<td>57±13</td>
<td>56±13</td>
<td>0.34</td>
<td>56±13</td>
<td>0.19</td>
<td>0.15</td>
</tr>
<tr>
<td>Men</td>
<td>432 (52%)</td>
<td>2369 (53%)</td>
<td>0.81</td>
<td>3484 (53%)</td>
<td>0.85</td>
<td>0.72</td>
</tr>
<tr>
<td>BMI (mean±SD)</td>
<td>29.2±6.1</td>
<td>29.6±6.1</td>
<td>0.033</td>
<td>29.7±6.3</td>
<td>0.57</td>
<td>0.045</td>
</tr>
<tr>
<td>Hypertension</td>
<td>432 (52%)</td>
<td>2365 (52%)</td>
<td>0.75</td>
<td>3509 (53%)</td>
<td>0.36</td>
<td>0.27</td>
</tr>
<tr>
<td>Dyslipidemia</td>
<td>435 (52%)</td>
<td>2339 (52%)</td>
<td>0.96</td>
<td>3559 (54%)</td>
<td>0.038</td>
<td>0.049</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>154 (19%)</td>
<td>676 (15%)</td>
<td>0.015</td>
<td>1010 (15%)</td>
<td>0.67</td>
<td>0.20</td>
</tr>
<tr>
<td>Current smoking</td>
<td>139 (17%)</td>
<td>671 (15%)</td>
<td>0.21</td>
<td>1073 (16%)</td>
<td>0.061</td>
<td>0.33</td>
</tr>
<tr>
<td>Family history of CAD</td>
<td>332 (41%)</td>
<td>1588 (35%)</td>
<td>0.015</td>
<td>2268 (34%)</td>
<td>0.33</td>
<td>0.009</td>
</tr>
<tr>
<td>Known CAD</td>
<td>116 (14%)</td>
<td>758 (17%)</td>
<td>0.037</td>
<td>1260 (19%)</td>
<td>0.35</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Chest pain</td>
<td>469 (56%)</td>
<td>2776 (62%)</td>
<td>0.28</td>
<td>3883 (59%)</td>
<td>0.003</td>
<td>0.034</td>
</tr>
<tr>
<td>Dyspnea</td>
<td>223 (27%)</td>
<td>1527 (36%)</td>
<td>&lt;0.0001</td>
<td>2442 (47%)</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Asymptomatic</td>
<td>125 (15%)</td>
<td>542 (12%)</td>
<td>0.021</td>
<td>809 (12%)</td>
<td>0.76</td>
<td>0.20</td>
</tr>
<tr>
<td>Coronary CTA only</td>
<td>476 (59%)</td>
<td>1229 (27%)</td>
<td>&lt;0.0001</td>
<td>2534 (39%)</td>
<td>&lt;0.0001</td>
<td>0.67</td>
</tr>
<tr>
<td>Coronary CTA with CAC</td>
<td>233 (28%)</td>
<td>2718 (61%)</td>
<td>&lt;0.0001</td>
<td>3115 (47%)</td>
<td>&lt;0.0001</td>
<td>0.18</td>
</tr>
<tr>
<td>Evaluation of bypass grafts</td>
<td>48 (5.7%)</td>
<td>356 (7.9%)</td>
<td>0.038</td>
<td>460 (7.0%)</td>
<td>0.064</td>
<td>0.73</td>
</tr>
<tr>
<td>Triple rule-out</td>
<td>56 (6.7%)</td>
<td>238 (5.3%)</td>
<td>0.08</td>
<td>531 (8.1%)</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Full thorax</td>
<td>109 (13%)</td>
<td>600 (13%)</td>
<td>0.79</td>
<td>970 (15%)</td>
<td>0.041</td>
<td>0.031</td>
</tr>
</tbody>
</table>

*P value <0.025 indicates significance after a Bonferroni adjustment. BMI indicates body mass index; CAC, coronary artery calcium; CAD, coronary artery disease, and CTA, computed tomography angiography.

†Control vs follow-up I; ‡follow-up I vs follow-up II; and †trend across time periods.
Follow-Up I Versus Follow-Up II
Compared with the maintenance period, there was a slight decrease in the percentage of diagnostic quality scans (94% versus 92.7%; \( P = 0.007 \)).

Multivariable Predictors of Target Radiation Dose (<10 mSv)
To assess the influence of various factors separately in predicting a target DLP of 714 mGy·cm or <10 mSv in follow-up II among patients undergoing retrospectively or prospectively gated coronary CTA, several multivariate logistic analyses were performed (Table 4).

On examining all patients in follow-up II (n=6577), the most significant variables associated with achieving ≤10 mSv were the use of lower tube voltage of 100 kVp (odds ratio [OR], 3.12; 95% confidence interval [CI], 2.653–3.668), non-retrospective gating (OR, 2.236; 95% CI, 1.970–2.540), BMI <30 kg/m\(^2\) (OR, 1.731; 95% CI, 1.489–2.012), high (>30) monthly scan volume (OR, 1.384; 95% CI, 1.209–1.584), and female sex (OR, 1.092; 95% CI, 0.964–1.237).

Among patients undergoing retrospective gating (n=2088), the most significant variables associated with achieving ≤10 mSv were the use of lower tube voltage of 100 kVp (OR, 1.365; 95% CI, 0.807–2.31), and female sex (OR, 1.059; 95% CI, 0.905–1.238).

Although significant differences were noted among the various manufacturers and models used among the sites during the study period with similar protocols, significant dose reduction was achieved among all groups with lowered tube voltage as depicted in Table 5.

Discussion
The results of this study demonstrate that adoption of newer dose-reduction technologies for coronary CTA scan acquisition was associated with reduction in radiation dose by 31%. Although continuous implementation of a best-practice algorithm resulted in sustained maintenance of previously attained median dose, the introduction of newer technologies was associated with incremental reduction. Combined with the previously reported 53% reduction during the first study period of the CQI, this represents a net 77% reduction of dose from July 2007 to April 2011. The achievement of a median DLP of 350 mGy·cm or 4.9 mSv (during the final bimonthly period) exceeded the goal of 10 mSv set during the maintenance period, primarily after adoption of newer technologies. Across scanner models and manufacturers, lowered tube voltage resulted in corresponding substantial dose reduction.
reduction. Additional effective educational approaches were stringent prescan heart rate control, decreased scan length, and ECG dose modulation for retrospective gating. The CQI feedback loop focused on issues such as regular dose monitoring, adequacy of patient preparation, appropriate choices of imaging protocols, and resultant image quality provides an unique opportunity to improve the practice of CCTA.

On multivariable analysis, reduction in scan tube potential from 120 to 100 kVp emerged as the strongest variable associated with achieving a target estimated dose <10 mSv among all patients, followed by nonretrospective gating (prospective and high-pitch spiral scanning) and lower BMI. Importantly, among patients undergoing retrospective gating, the strongest predictor of lowered dose was performance of the coronary CTA examination at a high-volume center (>30 scans per month). This analysis confirms prior research demonstrating the importance of these variables.12 The dose reduction program also included basic measures such as minimizing the length of the scan range, which was an independently important factor. Reduction of heart rate with β-blockade was emphasized to avoid motion artifacts and to allow narrowing of the scan acquisition time window to the maximal extent; heart rate reduction was an independent predictor of dose reduction.

The findings of this study support prior studies demonstrating an improvement in healthcare outcomes resulting from voluntary collaborative quality improvement programs.20–22 These results also extend previously described radiation dose observed in clinical coronary CTA practice, the effectiveness of dose reduction techniques, and preserved image quality.14,16,23–25 Most importantly, these results demonstrate the sustained effect of this intervention >3 years across a variety of centers providing real world clinical coronary CTA services.

Sequential scanning, also called prospective-triggered scanning, when combined with 100 kVp tube potential, enables

discussion.
Radiation Doses Among Computed Tomography Scanner Manufacturers and Models

| Siemens | 64-Slice | n=22, 14.8 (13.6, 16.8) | n=49, 8.4 (7.7, 9.3) | n=3, 6.9 (6.7, 10.7) | n=5, 4.9 (4.5, 6.7) |
| Dual source | n=670, 10.0 (7.7, 13.2) | n=722, 5.1 (4.1, 6.4) | n=383, 11.2 (7.8, 15.2) | n=308, 5.3 (4.4, 6.9) |
| High-pitch | n=124, 11.0 (8.2, 17.5) | n=96, 5.5 (4.1, 8.2) | n=960, 5.2 (4.2, 7.0) | n=1040, 2.8 (2.0, 3.6) |

| Phillips | 64-Slice | n=45, 16.4 (15.6, 18.5) | n=2, 7.1 (3.8, 10.3) | n=6, 15.7 (8.0, 18.0) | n=2, 13.7 (12.4, 14.9) |
| 664-Slice | n=161, 16.7 (10.7, 21.4) | n=225, 10.8 (7.7, 13.6) | n=1286, 14.5 (7.0, 21.9) | n=928, 6.7 (4.1, 11.3) |

| GE | 664-Slice | n=145, 18.3 (15.7, 21.4) | n=10, 8.5 (7.4, 14.9) | n=76, 15.4 (8.2, 18.9) | n=1, 7.5 |
| Toshiba | n=3, 12.5 (10.2, 14.7) | n=4, 5.9 (3.2, 8.8) | n=159, 6.8 (5.5, 9.4) | n=41, 4.0 (2.6, 4.6) |

Median radiation doses are indicated in bold font (25th, 75th percentiles).

dose reductions to the 2 to 5 mSv level in suitable patients.\textsuperscript{36-39} This technique was adopted by the majority of the sites by the end of this study. In some centers single heartbeat acquisitions using wide detector-array 320-slice and high-pitch dual source scanners were available, and these sites achieved the lowest median doses when all available techniques were combined. No significant decrease in the proportion of diagnostic scans was noted when comparing follow-up I and follow-up II periods. However, there was a nonsignificant trend toward a decrease in average quality rating, suggesting that clinicians were willing to make the trade-off between pretty pictures and diagnostic images for the sake of patient safety.

Clinical Implications

The enthusiasm for the potential cost savings and convenience of coronary CTA has been tempered by significant concerns about the doses of radiation received by patients. This study suggests that thoughtful interventions in a collaborative setting can result in significant improvement in the safety profile of coronary CTA. Thus, the value of radiation reduction techniques should be strongly emphasized during physician and technologist training, and physicians must demonstrate technical mastery of these methods as part of certification to provide and supervise coronary CTA scanning. In this study, in addition to adoption, the educational interventions that had the highest impact were lowered tube voltage, meticulous attention to heart rate control, and minimizing scan length. Finally, without monitoring of doses it is impossible to improve practice; thus, a dose recording and review process have been recommended in published clinical guidelines.\textsuperscript{11} Although radiation dose resulting from coronary CTA scans has been the focus of this study, it is important for practicing clinicians to be cognizant of total, cumulative radiation doses that a given patient is exposed to, including all routine and specialized cardiac and noncardiac imaging studies.

Study Limitations

It is important to consider the limitations pertinent to the methods of this study. Unlike a randomized controlled trial, our observational study design limits the conclusions that can be drawn about the causal relationship between the study intervention (the best-practice model) and the results. Additional factors extraneous to the study intervention could also have played a role.

Adoption of new scanner technology occurred at various points during the study period at each site, and the exact date of adoption could not be determined at all sites. It was also not possible to definitively distinguish between radiation dose lowering as a result of advances in CT technology versus educational intervention.

The method of estimating radiation dose used depends on the accuracy of measurements of CTDI\textsubscript{100} using an ionization chamber and standardized phantom on each scanner\textsuperscript{17}; a uniform supervised calibration was not performed by the study investigators at each site. However, because each site served as its own control, inaccuracies introduced by variations in calibration were likely minimized as these inaccuracies were likely of similar magnitude in the control, intervention, and follow-up periods. Comparison between the effective radiation doses in this study and other non-CT procedures such as single photon emission computed tomography is subject to the assumptions implicit in the European Commission conversion coefficient. The collected data did not include measurement of the width of the acquisition window during ECG-gated tube current modulation. We, therefore, cannot assess the contribution this made to radiation dose reduction, although we hypothesize that this is reflected in the effect of heart rate reduction.

We restricted the multivariable analysis of examining the most significant variables associated with target dose achievement to demonstrate the end result of both the educational intervention and the adoption of newer technologies because the effect of the former has already been reported previously.\textsuperscript{12} This strategy may confound hospital type and the impact of specific technological improvements to some extent.

In addition, the criteria for diagnostic image quality were focused on detection of stenosis, and not available for all patients at the beginning of the consortium. Because lower kVp results in better contrast enhancement intraluminally, the finding of retained image quality with reduced kVp would be expected. However, it is unclear whether individual plaque characteristics, such as remodeling index, plaque density, etc, are retained at lower kVp.
Conclusions
The findings of this study demonstrate that consistent application of currently available radiation dose-reduction techniques is associated with sustained reduction in the radiation dose received by patients undergoing coronary CTA in a statewide registry and that further substantial dose reduction is demonstrated after incorporation of new scanner technology. This accomplishment provides support for the use of collaborative, consortium-based quality improvement strategies for improving the quality of medical care.

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Dr Chinnaiyan received grant support from the American Heart Association; Dr Abidov is on the Speaker’s Bureau of and is a consultant to Astellas Pharma, Inc and received grant support from Sarver Heart Center, Tucson, AZ; Dr Raff received grant support from Siemens Healthcare; Dr Share received salary from Blue Cross/Blue Shield of Michigan. The other authors report no conflicts.

References


**CLINICAL PERSPECTIVE**

The enthusiasm for the potential cost savings and convenience of coronary computed tomography angiography has been tempered by significant concerns about the doses of radiation received by patients. This real-world study suggests that thoughtful interventions in a collaborative setting can result in significant radiation dose reduction. Thus, the value of radiation reduction techniques should be strongly emphasized during physician and technologist training and physicians must demonstrate technical mastery of these methods as part of certification to provide and supervise coronary computed tomography angiography scanning. In this study, in addition to adoption, the educational interventions that had the highest impact were lowered tube voltage, meticulous attention to heart rate control, and minimizing scan length. Finally, without monitoring of doses it is impossible to improve practice; thus, a dose recording and review process have been recommended in published clinical guidelines. Although radiation dose resulting from coronary computed tomography angiography scans has been the focus of this study, it is important for practicing clinicians to be cognizant of total, cumulative radiation doses that a given patient is exposed to, including all routine and specialized cardiac and noncardiac imaging studies.
Progressive Radiation Dose Reduction From Coronary Computed Tomography Angiography in a Statewide Collaborative Quality Improvement Program: Results From the Advanced Cardiovascular Imaging Consortium

Kavitha M. Chinnaiyan, Judith A. Boura, Ann DePetris, Ralph Gentry, Aiden Abidov, David A. Share and Gilbert L. Raff
and the Advanced Cardiovascular Imaging Consortium Coinvestigators

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## Appendix A. Sites and Scanner Types During Study Period

<table>
<thead>
<tr>
<th>Site</th>
<th>Clinical Champion</th>
<th>Type of Facility</th>
<th>Control May-June 2008</th>
<th>Follow-up I July 2008-June 2009</th>
<th>Follow-up II July 2009-Apr 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beaumont Hospital, Royal Oak</td>
<td>Kavitha Chinnaiyan, MD</td>
<td>Teaching, Tertiary, Large</td>
<td>Siemens SOMATOM Definition Dual Source 128 Slice CT</td>
<td>Siemens SOMATOM Definition Dual Source 128 Slice CT</td>
<td>Siemens SOMATOM Definition Flash</td>
</tr>
<tr>
<td>Borgess Medical Center</td>
<td>Mark Shaman, MD, Alex Sassani, MD</td>
<td>Teaching, Tertiary, Large</td>
<td>Toshiba Aquilion 64</td>
<td>Toshiba Aquilion 64</td>
<td>Toshiba Aquilion 64</td>
</tr>
<tr>
<td>Hackley Hospital</td>
<td>Ralph Ryan, MD</td>
<td>Teaching, Small</td>
<td>Siemens SOMATOM Definition Dual Source 128 Slice CT</td>
<td>Siemens SOMATOM Definition Dual Source 128 Slice CT</td>
<td>Siemens SOMATOM Definition Dual Source 128 Slice CT</td>
</tr>
<tr>
<td>Henry Ford Hospital</td>
<td>Chad Poopat, MD, Thomas Song, MD</td>
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