Measures to Reduce Radiation in a Modern Cardiac Catheterization Laboratory

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Background—X-ray use in the catheterization laboratory is guided by the principle of as low as reasonably achievable. In accordance with this principle, we reduced the default fluoroscopic frame rate from 10 to 7.5 frames/s and increased the emphasis on the use of low-dose acquisition starting January 1, 2013. We aimed to study the impact of these measures on the total air kerma during diagnostic catheterization (DC) and percutaneous interventions (PCI).

Methods and Results—Propensity matching based on age, sex, body surface area, total fluoroscopy time, and total acquisition time was used to select matched patients for 2012 and 2013, further stratified by DC or PCI. The total air kerma was subsequently compared between 2012 and 2013, separately for DC and PCI. Median total air kerma during DC in 2013 was 625 mGy, which was significantly lower than the corresponding values in 2012 (median, 798 mGy; P<0.001). Similarly, median total air kerma during PCI in 2013 was 1675 mGy, which was significantly less than corresponding values in 2012 (median 2463 mGy, P<0.001). On comparison of air kerma rates between corresponding projections in 2 years, we observed a significant reduction in fluoroscopy- and acquisition-based air kerma rates in 2013, after institution of radiation reduction measures in all projections.

Conclusions—With reduction in the default fluoroscopic frame rate and a greater use of low-dose acquisition, there has been a marked reduction in the total air kerma and air kerma rates for DC and PCI. (Circ Cardiovasc Interv. 2014;7:447-455.)

Key Words: ionizing radiation | radiation | radiation effects | radiation protection
WHAT IS KNOWN

• Angiographic procedures utilizing ionizing radiation like cardiac catheterization pose a significant health hazard to the operators, especially those who have been practicing for a long period of time.
• Although there have been several innovations that help monitor radiation dose and exposure in the catheterization laboratory, there have been relatively fewer developments in the area of radiation reduction.

WHAT THE STUDY ADDS

• We report the impact of simple radiation reduction measures on radiation dosimetry during diagnostic catheterization and percutaneous intervention, in a real-world modern catheterization laboratory that utilizes contemporary digital equipment.
• With reduction in the default fluoroscopic frame rate and a greater use of low-dose acquisition modalities, there has been a marked reduction in the total air kerma and air kerma rates for diagnostic catheterization and percutaneous interventions.

lower dose x-rays. Based on our observations of factors that govern radiation dosimetry, we developed a comprehensive initiative toward radiation dose reduction.

In this study, we report the impact of these radiation reduction measures on total air kerma and air kerma rates during diagnostic catheterization (DC) and percutaneous intervention (PCI) in a real-world modern catheterization laboratory that utilizes contemporary digital equipment. In addition, we evaluated the impact of these radiation reduction measures on radiation dosimetry in various projections, by using complex spatial modeling. This was important because currently there is poor understanding of precise alterations in the radiation dose with changes in the beam angulation. The impact of radiation reduction measures on total radiation dose, especially in steep angulations, is virtually unknown.

Methods

Study Population

All adult patients (>18 years) undergoing DC or PCI at the Cleveland Clinic between January 1, 2012, and July 31, 2013, were included. Only those patients who underwent elective procedures were included in the study. Patients presenting with acute myocardial infarction undergoing emergency procedures were excluded. In addition, patients were excluded if they underwent peripheral interventions, structural heart disease interventions, or catheterization using biplane angiography. Of the 7 cardiac catheterization laboratories dedicated for heart disease interventions, or catheterization using biplane angiography. Of the 7 cardiac catheterization laboratories dedicated for heart disease interventions, or catheterization using biplane angiography, 4 rooms possess the Siemens Artis Zee floor mounted system (installed August 2008). The remaining 1 room possesses the Siemens Artis Zee Zeeo multi-axis system (installed August 2008). The study was approved by the Cleveland Clinic Institutional Review Board.

Radiation Dose Reduction Initiative

On January 1, 2013, the catheterization laboratory administration rolled out a comprehensive initiative to reduce radiation doses to patients and physicians. Based on our observations of factors that govern radiation dosimetry, we developed this initiative toward radiation dose reduction. The components of this initiative included the following measures:

• Reduction of default fluoroscopic frame rate from 10 to 7.5 frames/s. The operators were given a choice to switch back to 10 frames/s at any point during the case, if they so desired.
• Greater emphasis on the use of low-dose acquisition in all catheterization laboratories.
• Greater emphasis on optimal radiation practices including use of less extreme angulations, maximal collimation, reduction in source-to-detector distance, increased field of view, and decreased geometric magnification by decreasing source-to-object distance.
• Review and critical appraisal of monthly radiation dosimetry of each interventional cardiology fellow by the cardiac catheterization laboratory director.

The total air kerma and air kerma rates were compared between the 2 study groups that included all patients from 2013 (postinitiative) and matched controls from 2012 (preinitiative).

Study Variables

Data were extracted from the SyngoDynamics using Siemens CARE Analytics software. Patients were excluded if there was an incomplete record of all radiation sequences during the procedure in the Siemens database. Although the term cine is still utilized in catheterization terminology, the modern digital systems are no longer cine based. The images that are acquired for storage are generally said to be captured in acquisition mode. Fluoroscopy is simply live imaging using lower radiation dose, which is usually not stored.

The data extracted included patient-specific variables such as age, sex, and body surface area along with image sequence-specific variables, such as imaging mode (fluoroscopy versus acquisition), projection angles, source-to-detector distance, source-to-object distance, x-ray pulse duration, frame rate, and imaging protocol. The nomenclature for the angulation was set a priori to ensure uniformity in the data analysis. Primary angulation referred to the left anterior oblique or right anterior oblique projection, with negative values denoting the right anterior oblique projections. Secondary angulation referred to the cranial–caudal projection, with negative values denoting the caudal projections.

The primary outcome variable was the total air kerma at the interventional reference point (IRP). IRP was defined as an imaginary point located 15 cm from the isocenter toward the source. According to the International Atomic Energy Agency, kerma (kinetic energy released in a material) is the sum of the initial kinetic energies of all charged ionizing particles liberated by uncharged ionizing particles in material of unit mass. The air kerma rate was defined as the ratio of air kerma at the IRP and the x-ray pulse duration (in seconds).

The equipment in the catheterization laboratory was calibrated in a standard fashion throughout the study duration. The equipment and the operators remained the same between the 2 study periods. In 2012, we used a default fluoroscopic frame rate of 10 frames/s and an acquisition frame rate of 10 frames/s. For a standard preset angulation, each machine was calibrated so as to deliver 29 nGy per pulse for fluoroscopy and 170 nGy per pulse for acquisition. In 2013, we used a default fluoroscopic frame rate of 7.5 frames/s and an acquisition frame rate of 10 frames/s. For a standard preset angulation in these settings, each machine was calibrated so as to deliver 29 nGy per pulse for fluoroscopy, 80 nGy per pulse for low-dose acquisition, and 170 nGy per pulse for normal-dose acquisition.

Data Analysis

Statistical analysis was performed using Stata version 13.1 (StataCorp, College Station, TX) and R version 3.0.1 (Comprehensive R Archive Network, Vienna, Austria). All continuous variables were expressed...
as medians with quartile 1 (Q1) to quartile 3 (Q3) ranges, and all categorical variables were expressed as proportions. Kruskal-Wallis and \( \chi^2 \) tests were utilized for comparison of unmatched continuous variables and categorical variables, respectively. The impact of radiation reduction measures was assessed by comparing the total air kerma along with air kerma stratified by fluoroscopy or acquisition between the 2013 and the matched 2012 cohorts. We selected matched controls for the 2013 cohort from the group of patients undergoing catheterization in 2012, using propensity score matching stratified by use of low-dose acquisition during the procedure. Propensity scores were generated using logistic regression analysis incorporating age, sex, body surface area, total fluoroscopy time, and total acquisition time as covariates. After generation of propensity score, matched sets were selected using a 5→1 greedy match algorithm.\(^2\) If an appropriate match could not be selected for a case, a 4-digit match on the propensity score was attempted. If an appropriate match could not be formed on the first 4 digits of the propensity score, then a 5-digit match was attempted. The process was repeated until matches were attempted on the first digit of the propensity score. If a case from 2013 could not be matched to a control from 2012 on the first digit of the propensity score, then this case was discarded from the matched analysis. All matching was performed without replacement to ensure that a control from 2012 was not selected twice into the matched data set. In addition, the balance in the matched baseline characteristics between the matched groups was assessed using standard techniques before comparing outcomes between these 2 groups. Paired t tests and McNemar tests were utilized for comparison of matched groups with respect to continuous variables and categorical variables, respectively.\(^2\)\(^3\)\(^4\) For the 2013 cohort of the total air kerma and air kerma rates between the 2 years, we did not exclude any procedures on the basis of the extent of utilization of the novel radiation reduction methods to avoid overestimation of the true effect on radiation dosimetry in our catheterization laboratory.

All fluoroscopic and acquisition sequences for 2012 were categorized into tertiles (low, medium, and high) based on the air kerma rate. Subsequently, radiation maps were created based on the proportion of high tertile air kerma rate acquisition in each projection. Red zone denotes projections where \(<26\%\) of the images were procured in the lowest tertile of air kerma rate. Yellow zone denotes projections where \(26\%\) to \(40\%\) of the image procurement occurred in the lowest tertile of air kerma rate. Green zone denotes projections where \(>40\%\) of the image procurement occurred in the lowest tertile of air kerma rate. All maps were created separately for fluoroscopy and acquisition modes. To compare the radiation dosimetry between 2012 and 2013, we created radiation maps for 2013, based on the tertile cut points determined for 2012. These maps helped determine the zones that were most affected by the radiation reduction measures instituted in our catheterization laboratory.

**Multivariable Analysis**

Multivariable linear regression analysis was performed with the logarithm-transformed air kerma rate as the dependent variable; 3-dimensional (3D) spatial maps were created separately for fluoroscopy or acquisition based on the above regression model. All patient-related and image sequence–related characteristics listed above were used as covariates. Source-to-detector distance was square root transformed to eliminate the leftward skew in its distribution. Linear splines were introduced at \(0^\circ\) for both primary and secondary angulation to incorporate asymmetry about the null. To study the direct impact of the radiation reduction measures, we incorporated only those sequences that in fact used these measures for the intervention- or diagnostic procedure in 2013. The sequences that utilized normal acquisition or higher fluoroscopic frame rates (>7.5 frames/s) in 2013 were excluded from the regression analysis. This was performed to understand the relationship between the spatial orientation and the newer radiation reduction methods without contaminating the data without projections that did not use these modalities. On the contrary, all available sequences in the 2012 cohort were included for multivariable analysis for facilitating direct comparison. The 3D spatial maps were constructed at the median values of all included covariates: source-to-detector distance=1100 mm; body surface area=2.0 m\(^2\); and magnification=1.2.

**Results**

A total of 2838 DC and 209 PCI constituted the 2013 cohort. From a procedural pool of 5032 DC and 369 PCI performed in 2012, we selected 2838 DC and 209 PCI using propensity matching as described above. Table 1 demonstrates the comparison of baseline characteristics of matched and unmatched cohorts. Although most of the covariates were similar between the unmatched populations, there was a significant difference in the total acquisition time that was adjusted using propensity matching. In 2013, low-dose acquisition was utilized in varying amounts in 131 PCI and 898 DC.

Table 2 demonstrates the comparison of total air kerma between 2013 and matched 2012 populations. Median (Q1–Q3) total air kerma during DC in 2013 was 625 mGy (351–1070), which was significantly lower than the corresponding values in 2012 (median [Q1–Q3], 798 [475–1389]; \(P<0.001\)). Similarly, median (Q1–Q3) total air kerma during PCI in 2013 was 1675 mGy (929–2712), which was significantly lower than the corresponding values in 2012 (median [Q1–Q3], 2463 [1345–4087]; \(P<0.001\)). As demonstrated in Table 2, both fluoroscopy-based and acquisition-based total air kerma rates were significantly reduced in 2013, as compared with corresponding matched population from 2012.

Table 3 demonstrates the comparison of total air kerma and air kerma rates between procedures performed using low-dose acquisition in 2013 and corresponding matched procedures performed using normal-dose acquisition in 2012. We observed a significantly lower fluoroscopy- and acquisition-based air kerma and air kerma rates during DC and PCI performed in 2013 as compared with matched procedures in 2012 (Table 3). Table 4 demonstrates the total air kerma and air kerma rates between procedures performed using normal-dose acquisition in 2013 and corresponding matched procedures performed in 2012. We observed that procedures using normal-dose acquisition in 2013 had significantly lower total air kerma as compared with matched procedures in 2012. In addition, we observed a significantly lower fluoroscopy- and acquisition-based air kerma and air kerma rates during DC and PCI performed in 2013 as compared with matched procedures in 2012 performed using normal-dose acquisition only (Table 4).

Based on the proportion of the lowest-tertile sequences in various projections, radiation maps were created as shown in Figures 1 and 2. The tertile cut points are shown in Table 5. These tertile cut points were determined from the radiation sequences of 2012. The same cut points were subsequently applied to the radiation sequences of 2013, to determine the direct impact of radiation reduction measures on radiation dosimetry. Figure 1 demonstrates the comparison of fluoroscopy-based air kerma rates between 2012 (Figure 1A) and 2013 (Figure 1B) for various projections. There was a significant reduction in fluoroscopy-based air kerma rates in 2013, after reduction of default fluoroscopic frame rate to 7.5 frames/s from 10 frames/s. Figure 2 demonstrates the comparison of acquisition-based air kerma rates between 2012 (Figure 2A) and 2013 (Figure 2B). Similar to the fluoroscopy-based air kerma rates, there was a significant reduction in the
acquisition-based air kerma rates in 2013, after a greater utilization of low-dose acquisition.

The 3D spatial maps for fluoroscopy and acquisition based on multivariable regression analysis are shown in Figures 3, 4, and Movie I and II in the Data Supplement. Figure 3 and Movie I in the Data Supplement demonstrate the comparison of modeled fluoroscopy-based air kerma rates (using 10 frames/s) in various projections in 2012 and the corresponding values (using 7.5 frames/s) in 2013. Similar to the observations made above, there was a considerable reduction in the fluoroscopy-based air kerma rates in 2013 in all projections after reduction in the default fluoroscopic frame rate. Figure 4 and Movie II in the Data Supplement demonstrate the comparison of modeled normal-dose acquisition–based air kerma rates in various projections in 2012 and the corresponding values with low-dose acquisition in 2013. We observed a marked reduction in the acquisition-based air kerma rates in all projections with the use of low-dose acquisition, as compared with normal-dose acquisition. Contrary to the existing belief, our study clearly demonstrates that the use of lower fluoroscopic frame rate and low-dose acquisition can lead to marked reduction in the total air kerma, even for projections involving steep angulations.

The International Commission on Radiological Protection recommends that radiation dose reduction can be brought about by 3 important steps: justification, optimization, and dose limitation. 8 Justification implies that any invasive procedure requiring use of ionizing radiation should yield a significantly higher benefit to the patient than the risk of the procedure and the hazards of radiation exposure. Optimization is the basis of the principle as low as reasonably achievable, which refers to measures that reduce the patient and personnel radiation exposure to a minimum, without jeopardizing the safety and the success of the procedure. The third element, dose limitation, refers to establishment of upper limits on the dose exposure to each member of the team, followed by critical appraisal of the current practices to ensure compliance with these established standards.

The last decade has witnessed the rise of digital imaging technology and new flat-bed panel detectors for image procurement, thereby replacing the old image intensifier.

### Discussion

Our study has evaluated the impact of several radiation reduction measures on total air kerma and air kerma rates in a modern catheterization laboratory that uses contemporary digital imaging technology. We demonstrated a marked reduction in total air kerma during DC and PCI, after institution of simple radiation reduction measures. Compared with the matched controls chosen from the period before institution of these measures, the reduction in total air kerma during DC and PCI were 22% and 32%, respectively. In addition, both fluoroscopy-based and acquisition-based total air kerma rates were significantly reduced in 2013, as compared with corresponding matched population from 2012. We created comparative 3D spatial maps for fluoroscopy and acquisition based on multivariable regression analysis to demonstrate reduction of air kerma rates for various projections. We observed a considerable reduction in the fluoroscopy-based air kerma rates in 2013 in all projections after reduction in the default fluoroscopic frame rate. In addition, we observed a marked reduction in the acquisition-based air kerma rates in all projections with the use of low-dose acquisition, as compared with normal-dose acquisition. Contrary to the existing belief, our study clearly demonstrates that the use of lower fluoroscopic frame rate and low-dose acquisition can lead to marked reduction in the total air kerma, even for projections involving steep angulations.

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The last decade has witnessed the rise of digital imaging technology and new flat-bed panel detectors for image procurement, thereby replacing the old image intensifier.
systems. Besides digital processing, the advantages of these flat-bed panel detectors include a small size, increased sensitivity to x-rays due to a higher detector quantum efficiency, and improvement in spatial resolution, particularly the peripheral field of view.25 Although systematic data on the impact of flat-bed panel detectors on radiation dose reduction are lacking in cardiac catheterization, it is assumed that there has been a significant reduction in radiation exposure to the patient and to the catheterization laboratory personnel.25,26 This has been derived from the use of flat-bed panel detectors in chest radiograph and skeletal radiograph, where this technology has resulted in ≥50% dose reduction.27 The other benefit of using digital imaging technology includes availability of multiple novel tools to reduce radiation dose,

Table 2. Comparison of Total Air Kerma Between 2013 and Matched 2012 Population

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>2013 (Low-Dose Acquisition)</th>
<th>2012 (Propensity-Matched Cohort)</th>
<th>( P ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic catheterizations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( n )</td>
<td>898</td>
<td>898</td>
<td></td>
</tr>
<tr>
<td>Total air kerma, mGy</td>
<td>690 (326–1364)</td>
<td>1033 (586–1921)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total fluoroscopy duration, s</td>
<td>690 (324–1247)</td>
<td>689 (338–1303)</td>
<td>0.6</td>
</tr>
<tr>
<td>Fluoroscopy-based air kerma, mGy</td>
<td>278 (103–696)</td>
<td>505 (207–1129)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fluoroscopy-based air kerma rate, mGy/s</td>
<td>0.44 (0.27–0.70)</td>
<td>0.77 (0.53–1.11)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total acquisition duration</td>
<td>59 (40–86)</td>
<td>63 (44–89)</td>
<td>0.07</td>
</tr>
<tr>
<td>Acquisition-based air kerma, mGy</td>
<td>363 (190–655)</td>
<td>483 (297–785)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Acquisition-based air kerma rate, mGy/s</td>
<td>5.84 (3.95–8.59)</td>
<td>7.89 (5.73–10.63)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Percutaneous interventions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( n )</td>
<td>131</td>
<td>131</td>
<td></td>
</tr>
<tr>
<td>Total air kerma, mGy</td>
<td>1823 (1010–3003)</td>
<td>2539 (1542–4288)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total fluoroscopy duration, s</td>
<td>1784 (947–3153)</td>
<td>1808 (1021–2773)</td>
<td>0.7</td>
</tr>
<tr>
<td>Fluoroscopy-based air kerma, mGy</td>
<td>1206 (626–2383)</td>
<td>1834 (1058–3195)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fluoroscopy-based air kerma rate, mGy/s</td>
<td>0.68 (0.48–0.99)</td>
<td>1.15 (0.83–1.61)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total acquisition duration</td>
<td>67 (47–99)</td>
<td>71 (52–96)</td>
<td>0.1</td>
</tr>
<tr>
<td>Acquisition-based air kerma, mGy</td>
<td>451 (276–806)</td>
<td>620 (402–972)</td>
<td>0.004</td>
</tr>
<tr>
<td>Acquisition-based air kerma rate, mGy/s</td>
<td>7.11 (4.91–10.30)</td>
<td>9.04 (6.35–12.53)</td>
<td>0.003</td>
</tr>
</tbody>
</table>

All values expressed as median (quartile 1–quartile 3 range).
without hampering image quality. However, a large majority of operators may be unaware of technical intricacies required to use these tools to their fullest potential. Dose optimization of the modern equipment is required to realize benefits from digitalization. The degree of radiation reduction is dependent on specific characteristics of the equipment being utilized. Therefore, optimization of the imaging protocols should be based on comprehensive assessment of dosimetric characteristics and the performance of radiation reduction tools of the equipment used.

Radiation dose during cardiac catheterization is dependent on several factors that may be considered unalterable, such as body surface area, procedural complexity, operator experience, and catheterization laboratory equipment. In addition, it is also highly dependent on factors that may be controlled by the operator, thereby providing avenues to minimizing radiation doses by substantial amounts. Kuon et al have demonstrated that routine use of less irradiating projections leads to a significant reduction in the mean exposure values to the patients and the operators. Theocharopoulos et al had recommended that the patient must be approached from the right-hand side as compared with the left-hand side, as the radiation backscatter is much reduced. In addition, they recommended reduction in tube voltage and milliamperage to reduce patient exposure. The latest equipment provides useful tools for monitoring dose in real-time and reducing the exposure time, virtual collimation on the last image hold, virtual centering without fluoroscopy, and automation of preselected projections.

Besides the use of good radiation practices, a formal training in radiation protection for interventional cardiologists has been shown to be effective in reducing radiation exposures to patients. Georges et al have demonstrated that a formal 2-day training program in radiation protection coupled with use of simple cost-free dose reduction techniques, such as low fluoroscopic and cine pulse rates, maximal collimation, and optimal x-ray tube/patient/intensifier distances, was associated with 50% reduction in radiation exposures to patients undergoing invasive cardiac procedures without any loss of diagnostic information. Several radiation safety organizations such as International Commission on Radiological Protection and International Atomic Energy Agency have focused on spreading awareness on radiation protection and established tools and formulated recommendations toward reducing radiation to lowest possible levels. In addition, they are responsible for regularly monitoring progress toward this goal.

**Strengths and Limitations**

To the best of our knowledge, this is the first study to characterize the impact of simple radiation reduction measures in a modern day catheterization laboratory in a real-patient setting. There is a conspicuous paucity of such data from laboratories that use flat panel detectors. Most of our knowledge about radiation reduction stems from older studies that used phantom models with older image intensifier-based systems. We have used a large amount of data to create predictive statistical models to forecast the air kerma rates in both study settings. Unique to this analysis was separate characterization
of radiation parameters of fluoroscopy versus acquisitions. Because all the characteristics that were entered into the predictive model were patient or procedure related, it is possible to accurately predict the amount of air kerma at the IRP, even before stepping on the foot pedal. This could be potentially used in creation of a Radiation Protection Advisor, which may be incorporated into the catheterization laboratory equipment, guiding the operator about avoidable high radiation zones.

Besides being limited by the traditional biases of an observational study, our study has a few other limitations. Although the total air kerma at the IRP provides a reliable measure of total dose delivered to the patient, it might be argued that there is little information about the extent of radiation exposure to the operator. However, the radiation protection for the operator cannot be treated independently from radiation protection for the patient, as they are correlated. The radiation exposure for the operator is secondary to the radiation scattered from the patient. Thus, if we aim to reduce the radiation dose delivery to the patient, the radiation scattered and absorbed by the operator would be consequently reduced. In other words, what is good for our patients, is likely good for us too! Other biases are possible, although unlikely since the equipment and the operators remained the same during the entire study period.

Table 5. Dose Tertiles for Acquisition and Fluoroscopy Established From the 2012 Data

<table>
<thead>
<tr>
<th>Category</th>
<th>Dose Tertiles, mGy/s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acquisition</strong></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>&lt;3.11</td>
</tr>
<tr>
<td>Medium</td>
<td>3.11–5.77</td>
</tr>
<tr>
<td>High</td>
<td>&gt;5.77</td>
</tr>
<tr>
<td><strong>Fluoroscopy</strong></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>&lt;0.36</td>
</tr>
<tr>
<td>Medium</td>
<td>0.36–1.35</td>
</tr>
<tr>
<td>High</td>
<td>&gt;1.35</td>
</tr>
</tbody>
</table>
As procedures in select catheterization laboratories were included in the analysis, there is a possibility of a case-selection bias in our study. In addition, our study may be limited by lack of direct assessment of angiographic image quality and image acceptability after institution of radiation reduction measures. Although a direct assessment of image quality was not available in our study, the rate of unsuccessful PCI in the 2 periods were not statistically different (5.6% in 2012, 4.0% in 2013, \( P=0.54 \)). This suggested that all operators were able to visualize all necessary aspects of the coronary anatomy that are generally thought to be critical for a successful intervention, without appreciable loss of image quality. As this was not an experimental study but a retrospective analysis of the available data, one could safely assume that all proceduralists adopted a strategy that would be paramount for a successful intervention rather than achieving radiation reduction alone.

**Conclusions**

There was a marked reduction in total air kerma during DC and PCI, after institution of radiation reduction measures including reduction of default fluoroscopic frame rate from 10 to 7.5 frames/s, use of low-dose acquisition, greater...
emphasize on optimal radiation practices, and critical appraisal of monthly radiation dosimetry of each interventional cardiology fellow by the cardiac catheterization laboratory director. Compared with the matched controls chosen from the period before institution of these measures, the reduction in total air kerma during DC and PCI were 22% and 32%, respectively. On stratification by various procedures, we observed a considerable reduction in both the fluoroscopy-based and the acquisition-based air kerma rates in 2013 for all procedures after institution of radiation reduction measures.

Disclosures

None.

References


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The version of the article, “Measures to Reduce Radiation in a Modern Cardiac Catheterization Laboratory” by Agarwal et al that published online August 5, 2014, and appears in the August issue (Circ Cardiovasc Interv. 2014;7:447–455) contained an error in Table 4. The entries in rows 3 through 9 in the table body have been replaced (Total air kerma, mGy; Total fluoroscopy duration, s; Fluoroscopy-based air kerma, mGy; Fluoroscopy-based air kerma rate, mGy/s; Total acquisition duration; Acquisition-based air kerma, mGy; and Acquisition-based air kerma rate, mGy/s).

This correction has been made to the online version of the article, which is available at http://circinterventions.ahajournals.org/content/7/4/447.