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Relationship of Beam Angulation and Radiation Exposure in the Cardiac Catheterization Laboratory

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Objectives The aim of this study was to analyze the relationship between beam angulation and air kerma in a modern cardiac catheterization laboratory.

Background Recent reports have identified the merits of reducing radiation scatter, an important determinant of radiation dose in the catheterization laboratory. Radiation scatter is poorly characterized in the context of catheterization laboratories using modern digital equipment. Understanding the principles of dosimetry may reduce the radiation exposure to patients, providers, and medical staff.

Methods Prospectively captured radiation data were extracted from a database of 1,975 diagnostic catheterizations (DCs) and 755 percutaneous coronary interventions (PCIs), which included 138,342 fluoroscopic and 35,440 acquisition (cine) sequences. Fluoroscopy and acquisition modes were categorized into tertiles based on the total air kerma measured at a standard reference point. Radiation maps were modeled according to the relative proportion of exposure in each projection.

Results Median air kerma during DCs and PCIs was 677 and 2,188 mGy, respectively. Fluoroscopy contributed to 66.3% of total dose during PCIs compared with 39.7% during DCs ($p < 0.001$). Fluoroscopy was more sensitive to changes in angulation with a rapid increase in total air kerma on small increases in beam angulation. Complex spatial maps were created to study the impact of angulation and other covariates on total air kerma. Besides beam angulation, body surface area was the strongest predictor of the total air kerma.

Conclusions This study uniquely describes radiation dosimetry using contemporary equipment in a real-world setting. Extreme angulations were associated with high air kerma values. Fluoroscopy compared with acquisition was more sensitive to changes in angulation, with relatively larger increases in total air kerma with small increases in steepness of the angulation. (J Am Coll Cardiol Intv 2014;7:558–66) © 2014 by the American College of Cardiology Foundation

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X-rays have officially been labeled as a "carcinogen" by the World Health Organization's International Agency for Research on Cancer, the Agency for Toxic Substances and Disease Registry of the Centers for Disease Control and Prevention, and the National Institute of Environmental Health Sciences (1–3). Over the past few decades, there has been a steady increase in the number of diagnostic and therapeutic procedures, that involve ionizing radiation, including x-rays, computed tomography, interventional radiology procedures, as well as catheterization laboratory–related diagnostic and therapeutic interventions. The modern catheterization laboratory is currently "the epicenter of contemporary medical radiological tsunami" (4). Therefore, the cardiology community bears the responsibility of minimizing radiation exposure to their patients and, also, to themselves and to their professional staff (5).

The principle of ALARA ("as low as reasonably achievable") has been proposed by the International Commission for Radiation Protection to guide responsible radiation use (6). The factors that affect the dose in interventional procedures are generally classified as patient related, equipment related, or procedure related (5). One of the most important procedure-related factors governing the amount of radiation scattered is the beam orientation and movement (5). Although radiation mapping was developed in the past (7), high-quality data detailing the radiation dose with modern catheterization laboratory equipment in real-life patient settings do not currently exist. All modern catheterization laboratories use flat-panel detectors with digital acquisition rather than the old image-intensifier systems. Most of our understanding about the predictors and parameters of the radiation dose in the catheterization laboratory arises from these old studies that were based on older systems and were performed using phantom models. Therefore, we present an analysis of radiation dosimetry with 3-dimensional visualization models in a real-world experience with contemporary catheterization laboratory equipment.

Methods

Study population. All adult patients (older than 18 years of age) undergoing a diagnostic catheterization (DC) or percutaneous coronary intervention (PCI) at the Cleveland Clinic between January 1, 2012, and July 31, 2012, were considered for inclusion. Patients were excluded if they underwent peripheral interventions, structural heart disease interventions, or catheterization using biplane angiography. The study was approved by the Cleveland Clinic Institutional Review Board.

Study variables. Data were extracted from the *syngo* Dynamics using Siemens CARE (Combined Applications to Reduce Exposure) analytics software (Siemens Medical Solutions, Malvern, Pennsylvania). Although the term *cine* is still used 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 an acquisition mode. Fluoroscopy is simply live imaging using a lower radiation dose, which is usually not stored.

The data extracted included patient-specific variables such as age, sex, and body and surface area (BSA) along with image sequence–specific variables such as imaging mode (fluoroscopy vs. acquisition), projection angles, source-to-detector distance (SID), 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 (LAO) or right anterior oblique (RAO) projection, with negative values denoting the RAO 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 rate at the interventional reference point (IRP). The 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 (8). The air kerma rate was defined as the ratio of air kerma at the IRP and the x-ray pulse duration (in seconds). Two parameters of dose are useful for characterizing patient and physician exposure: the air kerma at the IRP and the dose-area product (DAP). Because DAP is determined by operator behavior and by variables that are not under the operator's control, it is challenging to identify a cutoff DAP that could be labeled as high. Although DAP may be a better measure of the patient's stochastic risk of an adverse radiation-related event, it has been demonstrated that the correlation between DAP and the absorbed dose determined using thermoluminescent detectors is rather poor (9). Based on these reasons, we chose to use the air kerma rate at the IRP as the primary outcome variable of interest.

Abbreviations and Acronyms

BSA = body surface area
DAP = dose-area product
DC = diagnostic catheterization
IQR = interquartile range
IRP = interventional reference point
LAO = left anterior oblique
PCI = percutaneous coronary intervention
RAO = right anterior oblique
SID = source-to-detector distance

The equipment in our catheterization laboratory was calibrated in a standard fashion throughout the study duration. In 2012, we used a fluoroscopic frame rate of 10 frames/s, and an acquisition frame rate of 15 frames/s. For a standard pre-set angulation, each machine was calibrated to deliver 29 nGy/pulse for fluoroscopy and 170 nGy/pulse for acquisition.

Data analysis. Statistical analysis was performed using Stata version 12.1 (StataCorp, College Station, Texas) and