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EDITORIAL COMMENT

Radiation Dose in Percutaneous Coronary Intervention

OUCH . . . Did That Hurt?*

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The cumulative exposure to ionizing radiation from medical imaging is increasing with attention now focused on all aspects of radiation safety (1). In this issue of *JACC: Cardiovascular Interventions*, Fetterly et al. (2) present their study on the factors that influence radiation dose during percutaneous coronary interventions (PCI). Interventional cardiologists have a variety of tasks to master, and management of radiation dose must be among them.

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All cardiac catheterization laboratories should have a radiation safety program and a goal to reduce radiation exposure as low as is reasonably achievable (3). To justify exposure, a basic principle of radiation protection, is to ensure the procedure is indicated (3,4). Dose optimization for fluoroscopic imaging is similarly important (5,6).

Proper assessment of radiation dose is a prerequisite for its management. Fluoroscopic time (min) does not include cine imaging and, therefore, alone, is not a useful descriptor of patient radiation dose (7). Total air-kerma at the interventional reference point ($K_{a,r}$, Gy) is the procedural cumulative air-kerma (X-ray energy delivered to air) at the interventional reference point. $K_{a,r}$ is used to monitor patient dose burden as it is associated with threshold-dependent deterministic skin effects (8) (Fig. 1). Air-kerma area product (P_{KA}, Gy/cm^2) is the cumulative sum of the product of instantaneous air-kerma and X-ray field area. P_{KA} is used to monitor the linear, nonthreshold patient dose burden associated with potential stochastic effects (e.g., radiation-induced cancer). Since 2006, interventional X-ray systems have been required to report $K_{a,r}$ and P_{KA}. Peak skin dose (Gy) is the maximum dose received by any area of a patient's skin. Although there is no currently available method to measure peak skin dose, it can be estimated by a qualified physicist if air-kerma and X-ray geometry details are known (7).

Medical imaging with ionizing radiation requires some risk to the patient (9). In the catheterization laboratory, staff and operator are exposed to lower single but higher cumulative radiation doses than the patient as well as nonradiation health issues (10,11). It is the individual's responsibility to wear dosimeter(s), with effective dose estimates based upon the number and location of dosimeters (3,12).

An inclusive radiation safety program protects the operator and staff by protecting the patient and vice versa. In addition to the standard operator protective garment, radiation-specific eye protection has been shown to be effective (3,13). Both transparent ceiling-mounted shielding and below-table-mounted shielding should be used routinely (14,15). Disposable radiation-absorbing patient sterile drapes may also help to reduce staff dose (16). Current X-ray systems are designed to assist in effective dose management (17). These features include pulsed fluoroscopy, on-screen dose display ($K_{a,r}$, P_{KA}), and stored fluoroscopy. The quality of the X-ray image is a function of multiple patient, procedure, and equipment variables. Significant variation in image quality and dose between individual laboratories has been identified (12,18). Knowing your equipment and working with a qualified physicist is essential for dose optimization. Certain states require training for personnel involved in fluoroscopy with training recommendations published (3,19).

Fetterly et al. (2) retrospectively assessed contributing factors to the procedural dose received by over 1,800 patients undergoing PCI. Dr. Fetterly, a medical physicist, used the total air-kerma at the reference point ($K_{a,r}$, Gy) to estimate peak skin dose. Patient, procedural, and operator imaging practices influenced the doses. The patient's size influenced dose, emphasizing the need for specific size-based X-ray programs to address the relationship between dose and image quality. Patients with peripheral vascular disease or previous bypass surgery received higher doses but renal insufficiency and diabetes were not a factor. Procedural complexity influenced dose, with PCI in the circumflex artery and for chronic total occlusions associated with increased dose. Of the 1,827 patients, 156 had the radial approach with no dose increase; this small number, with potential bias toward the more experienced operator for challenging cases, limits interpretation. Increased operator experience, as assessed by volume, was associated with lower patient dose. Though fellows were involved in 97% of the cases, those procedures performed by the higher volume attending were associated with lower patient dose.

The significance of the study should not be lost in the specifics. Though individual factors for dose reduction are

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Figure 1. Adverse Radiation Skin Effects

Erythema and epilation present, on patient's back, 1 month after complex chronic total occlusion percutaneous coronary intervention, with $K_{a,r}$ of 11.8 Gy.

Table 1. Radiation Dose Management in PCI

Pre-procedure
Radiation safety program for catheterization laboratory
Dosimeter use, shielding, training/education
Imaging equipment and operator knowledge
On-screen dose assessment
Dose saving: stored fluoroscopy, adjustable pulse and frame rate, and last image hold
Pre-procedure dose planning
Assess patient and procedure including patient's size and lesion(s) complexity
Informed patient with appropriate consent
Procedure
Limit fluoroscopy: step on petal only when looking at screen
Limit cine: store fluoroscopy when image quality not required
Limit magnification, frame rate, and steep angles
Use collimation and filters to fullest extent possible
Vary tube angle when possible to change skin area exposed
Position table and image receptor: X-ray tube too close to patient increases dose; high image receptor increases scatter
Keep patient and operator body parts out of field of view
Maximize shielding and distance from X-ray source for all personnel
Manage and monitor dose in real time from beginning of case
Post-procedure
Document radiation dose in records (fluoroscopy time, $K_{a,r}$, P_{KA})
Patient and referring physician notification for high dose
$K_{a,r} > 5$ Gy, chart document; inform patient; arrange follow-up
$K_{a,r} > 10$ Gy, qualified physicist should calculate skin dose
Peak skin dose >15 Gy, Joint Commission sentinel event
Adverse skin effects should be referred to appropriate consultant

$K_{a,r}$ = total air-kerma at reference point; PCI = percutaneous coronary intervention; P_{KA} = air-kerma area product.

important, it is essential to develop a culture of radiation safety. From 1997 to 2009, there was a 55% reduction in the mean procedural patient dose for PCI at the Mayo Clinic. Formal training for the interventional fellows is required on X-ray systems and radiation safety, despite no local or state mandate. Though not identified as a contributor to dose reduction in the study, Fetterly et al. (2) emphasize the potential benefit of pre-procedure dose planning as well as techniques for dose reduction during the procedure (3–5). Table 1 outlines a comprehensive approach to patient dose management including pre-procedure assessment, procedural dose management, and post-procedure follow-up that should be standard practice in interventional laboratories today (3).

During a PCI, the operator hears an "ouch" and reacts. Though radiation dose provides no such response, the potential long-term effects are far more significant than a painful needle stick. Therefore, it is the responsibility of the interventional cardiologist to use the didactic (written and tutorial) and personnel (qualified physicist and radiation safety officer) resources available, apply them to the patient with pre-procedure planning, and practice, from the beginning of the case, optimal radiation dose management.

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