Technical Principles for Cardiac Procedures

Charles Chambers, MD
Penn State Hershey Heart and Vascular Institute, Hershey, PA

SUMMARY

The cumulative exposure to ionizing radiation from medical imaging is increasing with attention now focused on all aspects of radiation safety. For invasive cardiology, both diagnostic and therapeutic/interventional, the complexity of the patient as well as the opportunities for percutaneous improvement in patient care have heightened the importance of, and ultimate awareness for, radiation safety. Procedure justification and assuring the right test is done on the right patient for the right reason with a plan in place for patient care decisions to integrate test results into the patient's care plan is essential for all practitioners treating all patients. This is particularly applicable to the cardiology patient undergoing multiple procedures utilizing ionizing radiation.

All cardiac catheterization laboratories should have a radiation safety program with the goal to reduce radiation exposure/patient dose. As low as reasonably achievable (ALARA) represents best procedure practice [1]. Dose optimization for fluoroscopic imaging is required throughout the entire procedure, not just when high doses are identified. The interventional cardiologist has a variety of tasks to master, and management of radiation dose must be among them. Through attention to radiation safety, significant dose reduction to our patients can occur. By providing the best care for the patient, a safer environment is created for the operator and staff to the benefit of all.

INTRODUCTION

The annual patient radiation dose from medical imaging has increased threefold since 1982, with cardiovascular dose alone increasing approximately 20 percent. With this increased "risk," patients have similarly seen dramatic gains in benefits. The population risk of cardiovascular death has decreased to 188/100,000, an improvement of threefold since the 1950s. Though these gains are not solely created through ionizing radiation techniques, the exact risk from radiation exposure is similarly unclear. Nonetheless, this dramatic increase in radiation from medical imaging has appropriately generated attention toward radiation safety. This article will address the technical principles for cardiac procedures, both diagnostic and therapeutic/interventional, recognizing best practices for radiation safety in the cardiac catheterization laboratory.

DOSE ASSESSMENT AND RADIATION EFFECTS

In order to appreciate dose reduction, an understanding of what we are tracking is in order. Assessment of radiation dose in the cardiac catheterization laboratory is much more than fluoroscopy time (FT, min), which does not take into account cine imaging, frame rate, angulations, patient size, etc. While FT still should be tracked, it is critical that dose also be tracked. This is why, since 2006, all fluoroscopic equipment sold in the United States has additional parameters to identify patient dose measured, recorded and displayed during the procedure.

The two standard parameters reported on interventional fluoroscopic equipment as of 2006 are 1) Total Air Kerma at the Interventional Reference Point ($K_{a,r}$, Gy) and 2) Air Kerma Area Product (P_{KA}, Gy cm^2) [2]. $K_{a,r}$, also referred to as Cumulative Air Kerma (CAK), is the procedural cumulative air kerma (X-ray energy delivered to air) at the interventional reference point. This identifies associated skin injury, called deterministic effects. This dose-related, threshold-dependent, radiation effect is rarely severe but requires appropriate precautions [3]. P_{KA} is the product of air kerma and the X-ray field, also referred to as Dose Area Product (DAP) and Kerma Area Product (KAP). P_{KA} is used to monitor the potential for genetic defects or cancer risk over time, called stochastic effects. Cancer risk is population based and linear, non-threshold, realizing all radiation may have some risk. There is no current method to measure peak skin dose (PSD) during the case. A qualified medical physicist should be notified early to calculate PSD, if high dose is delivered to a patient.

LABORATORY ENVIRONMENT AND TRAINING

All cardiac catheterization laboratories should have a radiation safety program with active participation from the physicians, staff, and medical physicists [4]. Radiation safety should be an integral component of each cardiac catheterization laboratory's Quality Assurance/Quality Improvement (QA/QI) program. Per the 2011 ACC/AHA/SCAI PCI Guidelines [5], all laboratories are required as a class I recommendation to have an independent QA/QI program, including discussion of the correct processes for radiation safety, review of laboratory procedure doses, presentation of high dose cases and analysis of potential adverse effects topics for the regular QA/QI meetings.

All interventional cardiologists should apply two basic principles of radiation protection to their practice: 1) ensure procedure justification, such that no patient receives radiation without potential benefit and; 2) reduce radiation exposure to as low as reasonably achievable (ALARA). Procedure justification requires all practitioners to ensure thoughtful consideration for all procedures that expose patients to radiation, especially when repetitive procedures are involved. In this context, it is essential to enhance awareness of medical practitioners regarding appropriate use criteria [6] to maximize study benefit within the parameters of potential radiation risk.

Reducing radiation exposure utilizing the ALARA principle requires standardization of training. Though only certain states mandate fluoroscopy training, everyone should receive radiation dose management and safety training commensurate to their responsibilities. For board certification, interventional cardiologists must pass an examination which includes physics and radiation safety questions [7]. The following is recommended by the National Council on Radiation Protection & Measurements (NCRP) [2]:

1. The catheterization laboratory radiation safety education program should be coordinated with the hospital radiation safety officer, hospital medical or health physicist, or an outside consultant. The following components, with appropriate documentation, are required:
    a. initial didactic training or verification of prior training for all physicians and staff using fluoroscopy with periodic updates
    b. hands-on training for newly hired operators and current operators on newly purchased equipment
2. The didactic program should address:
    a. physics of X-ray production and interaction
    b. technology and modes of operation of the fluoroscopy machine
    c. characteristics and technical factors affecting image quality in fluoroscopy
    d. dosimetry, quantities and units
    e. biological effects of radiation
    f. principles of radiation protection in fluoroscopy
    g. applicable federal, state and local regulations and requirements
    h. techniques to minimize patient and staff dose

Staff protection equates to patient protection and vice versa. Establishing a culture of radiation safety in the catheterization laboratory starts with proper use of the individual dosimeter(s). Appropriate use of protective garments will stop approximately 95 percent of the scattered radiation. Radiation glasses should be worn by high-volume operators as posterior subcapsular cataracts may occur as a deterministic effect. To be effective, glasses must fit properly and have 0.25 mm lead equivalent protection with additional side shielding. Ceiling-mounted and below-table shielding, when appropriately positioned, are effective and both should be used routinely.

Advanced procedures require advanced technology. Current fluoroscopic X-ray systems offer features for dose management including frame rate adjustment, virtual collimation, last image hold, storing fluoroscopy sequences and real-time dose display. Having the technology but not understanding its use equates to not having the technology, so all operators must familiarize themselves with this sophisticated equipment. Image quality is a function of multiple patient, procedure and equipment variables. As a general rule, image quality and radiation dose are tightly woven. Automatic dose rate controls increase dose for a specific patient size in a specific projection to achieve adequate image quality. Knowing the equipment and working with a qualified medical physicist are essential for dose optimization. In order to address both operator radiation exposure as well as physical occupational hazards, technology advances are being explored including robotic systems for diagnostic and interventional procedures, as well as magnetic navigation systems for electrophysiologic ablation procedures.

PROCEDURE BASED RADIATION DOSE MANAGEMENT

The potential benefits for establishing a radiation safety-conscious environment are seen. The Mayo clinic succeeded in a 40 percent radiation dose reduction CAK in patients over a 3-year period by implementing a culture and philosophy of radiation safety in the catheterization laboratory [8]. In addition to the training parameters outlined previously, procedure-based dose management should be performed. This involves pre-procedure, procedure and post-procedure components as outlined in other sections.

Pre-procedure planning is an essential component to radiation dose management. The cardiology patient is often known either to the operator or the operator's practice and will be an active patient post-procedure; this may enhance the physician/patient relationship. Specific patient populations, such as women and adults with structural heart disease, may pose specific concerns that need to be addressed [4]. High-risk patients include those who are obese or have complex disease or recent fluoroscopic procedures — within 30–60 days. Informed consent should include radiation safety information with a description of potential risks particularly in the high-risk patient.

During the case, the physician should manage dose from the outset. The staff should notify the physician when $K_{a,r}$ is in excess of 3 Gy and then every 1 Gy thereafter. When high-dose radiation has been administered, the operator must balance risk with benefit to proceed [9]. For the operator and staff, developing good techniques is essential. It is important to use fluoroscopy only when looking at the monitor and limit cine imaging. Steep angles, frame rate, collimation, protective shielding, and table and image receptor height are all important variables during the procedure. Operator and staff must maximize their distance from the X-ray tube (the inverse-square law — *a specified physical quantity or intensity diminishes in intensity inversely proportional to the square of the distance from the source*), which is of particular importance for radial access cases. All appendages, operator and patient, should be out of the imaging field. As a practical approach, radiation exposure may be reduced by remembering the acronym **"DRAPED"**:

D	Distance	Inverse square law, primarily for the operator and staff
R	Receptor	Keep image receptor close to patient and collimate
A	Angles	Avoid steep angles
P	Pedal	Keep foot off pedal except when looking at the monitor
E	Extremities	Keep patient and operator extremities out of the beam
D	Dose	Avoid cine, adjust frame rate, wear personal dosimeter

Post-procedure, the cardiac catheterization reports should include all available radiation parameters: FT (min), $K_{a,r}$, (Gy), and P_{KA}, (Gycm$^{2)}$. Patient notification, chart documentation, and communication with the primary care provider should occur following procedures with high radiation dose. For $K_{a,r}$ > 5 Gy (P_{KA}>500 Gy cm^2), patients should be educated regarding potential skin changes (e.g., a red patch on the back) with 30-day phone call follow-up and office visit as required. For $K_{a,r}$ > 10 Gy (P_{KA} >1,000 Gy cm^2), a qualified medical physicist should promptly calculate PSD with skin examined at two to four weeks. The Joint Commission identifies peak skin doses>15 Gy as a Sentinel Event; hospital risk management and regulatory agencies should be contacted within 24 hours. Suspected tissue injury should be referred to a specialist made aware of potential radiation etiology. A biopsy should be performed only if required, as the biopsy "wound" may potentially be more severe than the radiation effects.

CONCLUSION

Establishing a radiation safety-conscious environment in the cardiac catheterization laboratory for all procedures, diagnostic and therapeutic/interventional, should be a collaborative effort involving physicians, staff, medical physicists, quality assurance personnel and hospital administration. Establishing a safe radiation practice improves patient, staff and physician safety. All practitioners must play a role in ensuring procedure justification where the right person is getting the right test for the right reason. In the cardiac catheterization laboratory as well as peri-procedure, the interventional cardiologist, as the person responsible for all aspects of patient care, must be actively involved in managing radiation dose to maximize patient safety and procedural outcomes.

REFERENCES

1. Hirshfeld JW Jr, Balter S, Brinker JA, Kern MJ, Klein LW, Lindsay BD, Tommaso CL, Tracy CM, Wagner LK, Creager MA, et al. ACCF/AHA/HRS/SCAI clinical competence statement on physician knowledge to optimize patient safety and image quality in fluoroscopically guided invasive cardiovascular procedures, A report of the American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence and Training. JACC 2004; 4:2259-2282. Available at: http://circ.ahajournals.org/content/111/4/511.full. Accessed September 25, 2014.

2. NCRP Report No. 168. Radiation dose management for fluoroscopically-guided interventional medical procedures: National Council on Radiation Protection & Measurements; 2010. Available at: http://www.ncrponline.org/Publications/Press_Releases/168press.html. Accessed September 25, 2014.

3. Stecker MS, Balter S, Towbin RB, Miller DL, Vano E, Bartal G, Angle F, Chao CP, Cohen AM, Dixon RG, Gross K, Hartnell GG, Scheuler B, Statler JD, de Baere T, Cardella JF. Guidelines for Patient Radiation Management. JVIR 2009; 20: S263-S273. Available at: http://www.jvir.org/article/S1051-0443(09)00344-3/fulltext. Accessed September 25, 2014.

4. Chambers CE, Fetterly K, Holzer R, Lin PJP, Blankenship JC, Balter S, Laskey WK. Radiation Safety Program for the Cardiac Catheterization Laboratory. Cath and Card Interv. 2011 77: 510-514. Available at: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CDYQFjAA&url=http%3A%2F%2Fwww.scai.org%2Fasset.axd%3Fid%3D9401c662-81a8-4589-b1f8-1c0c1647c059%26t%3D&ei=UkMgVNTqJoKMyASR04LIDg&usg=AFQjCNFdC86IuF80cX90Hf_wMIifEsX8dw. Accessed September 25, 2014.

5. Levine, GL, Bates ER, Blankenship JC, Bailey SR, Bittl JA, Cercek B, Chambers CE, et al. 2011 ACCF/AHA/SCAI Guidelines for Percutaneous Coronary Intervention. JACC, 2011; 58:44-122 (7 Nov

2011). Available at: http://content.onlinejacc.org/article.aspx?articleid=1147816. Accessed September 25, 2014.

6. Patel MR, Bailey SR, Bonow RO, Chambers CE, et al. ACC/SCAI/AATS/ACCP/AHA/ASE/ASNC/HFSA/HRS/SCCM/SCCT/SCMR/STS 2012 Appropriate Use Criteria for Diagnostic Catheterization. JACC, 2012; 59:1-33. Available at: http://content.onlinejacc.org/article.aspx?articleid=1182705. Accessed September 25, 2014.

7. Jacobs AK, Babb JD, Hirshfeld JW, Holmes DR. COCATS Task Force 3: Training in Diagnostic and Interventional Cardiac Catheterization. JACC*,* 2008;51: 355-361. Available at: http://content.onlinejacc.org/article.aspx?articleid=1187224. Accessed September 25, 2014.

8. Fetterly KA, Mathew V, Lennon R, Bell MR, Holmes DR, Rihal CS. Radiation dose reduction in the invasive cardiovascular laboratory implementing a culture and philosophy of radiation safety. J Am Coll Cardiol Intv. 2012;5(8):866-873. Available at: http://interventions.onlinejacc.org/article.aspx?articleid=1352152. Accessed September 25, 2014.

9. Miller DL, Vano E, Bartel G, Balter S, Dixon R, Padovani R, Schueler B, Cardella JF, de Baer T. Occupational Radiation Protection in Interventional Radiology: A Joint Guideline of the Cardiolvascular and Interventional Society of Europe and the Society of Interventional Radiology. Cardiovasc Intervent Radiol 2010;33:230-239. Available at: http://link.springer.com/article/10.1007/s00270-009-9756-7/fulltext.html. Accessed September 25, 2014.