Occupational Exposure and Adverse Effects in the Radiologic Interventional Setting

Cannon Walden, BS, R.T.(R)(VI)

Professionals who work in an occupation involving radiological procedures can be at risk for exceeding annual radiation dose limits and the resulting long-term adverse health effects it causes.[1-18] However, overexposure to radiation and the resulting adverse effects might be avoided with proper radiation protection, increased radiation knowledge, and adherence to safety practices. The literature supports this approach, suggesting ways for those most at risk for radiation-related health illnesses to prevent them.

Radiologists Receive Higher Doses

With the potential for protracted fluoroscopy use during an interventional procedure, all staff in the suite are at risk for radiation exposure. However, because of the minimal distance between a physician and the patient, the physician's unintended dose is the highest.[2,5,7,8] Nurses are second closest to the source of scatter radiation and receive the next highest dose, and radiologic technologists receive the third highest unintended dose.[2,5,7,8]

In a 2013 study, Chida et al acquired the annual occupational dose for all workers in an interventional cardiology setting with the use of the effective dose formula and dose equivalent (see **Box**).[2] Each worker in the study wore 2 dosimetry badges: one under the personal lead apron (0.35-mm lead equivalent) at the chest or waist, and one outside the personal lead apron at the neck. $Dc_{1.0}$ was the chest or waist badge dose under the lead apron at 1-cm dose equivalent, $Dn_{1.0}$ was the neck badge dose outside the lead apron at 1-cm dose equivalent, and $Dn_{0.07}$ was the neck badge dose outside the apron at 70 µm dose equivalent.[2] The results showed that physicians received the highest doses, and technologists received the lowest dose (see **Table**).[2]

Box

Effective Dose and Dose Equivalent Formulas[2]

Effective dose $= 0.89 \times Dc_{1.0} + 0.11 \times Dn_{1.0}$
Dose equivalent $= 1.00 \times Dn_{0.07}$

The International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements established a standard annual occupational exposure limit of 50 mSv per year for the whole body (stochastic); the groups also set 150 mSv for the lens of the eye and 500 mSv for the skin, hands, and feet (nonstochastic).[2,5-8] The established lifetime effective dose limit—age in years × 10 mSv—is intended to be proportional to the risk of radiation-induced cancers and associated diseases. A busy interventional radiologist who takes all appropriate radiation safety precautions is unlikely to reach the set standards for occupational dose limits.[5-8]

Radiation-related Health Risks

According to some studies, even radiation dose levels below established occupational limits can present risk for adverse health effects.[1-18] An increased incidence of cataracts, cancer, and diseases, such as nonmalignant thyroid nodular disease and parathyroid adenoma, correlate with

Table

Annual Occupational Dose in millisieverts per year[2]

	Annual Mean ± SD Effective Dose (Range)	Annual Mean ± SD Dose Equivalent (Range)
Physicians	3.00 ± 1.50 (0.84-6.17)	19.84 ± 12.45 (7.0-48.5)
Nurses	1.34 ± 0.55 (0.70-2.20)	4.73 ± 0.72 (3.9-6.2)
Radiologic Technologists	0.60 ± 0.48 (0.02-1.43)	1.30 ± 1.00 (0.2-2.7)

Abbreviation: SD, standard deviation.

long-term radiation exposure.[8,16] Klein et al reported that the biological effects of radiation reaffirm the utility of the linear no-threshold model of radiation risk for solid cancers. This hypothesis states that any radiation dose carries with it an associated risk of cancer induction and that the risk increases with higher doses.[8] Radiation dose for occupational workers, for example, varies depending on the caseload and length of procedures.

Fluoroscopy-guided diagnostic procedures have become lengthier and more complex, require the use of additional radiation, and frequently require the use of imaging views that are unfavorable for the operator with regard to occupational exposure.[4,8,16] Unfavorable imaging views result when the fluoroscopy tube angles away from the typical vertical position and generates scatter from the patient directing it toward a nearby worker.[1] Procedures that might result in high exposure to workers include anything that lasts a substantial amount of time and encompasses examinations that involve intervention (eg, embolization, thrombolysis, angioplasty).[1]

Conclusive findings have not been established for determining radiation-induced cancers, although evidence has been reported in radiation-induced settings. The U.S. Radiologic Technologist Study, underway since 1982, is the largest study incorporating medical professionals who are exposed to ionizing radiation. The study's goal is to understand the link between repeated low-dose radiation exposure and cancer and other health conditions. Along these lines, Preston et al reviewed cancers in atomic bomb survivors and found that an exposure greater than 1 Sv was associated with an increased risk of tumors in the brain and central nervous system.[8]

When radiation protection tools are absent, workers in the interventional radiology setting are at risk for lens opacity, otherwise known as *cataracts*.[3,5,14,15] Lens opacities, which cause visual impairment, are classified into 3 forms according to their anatomical location: nuclear, cortical, and posterior subscapular.[3] Posterior subscapular, the least common form, is most notably associated with ionizing radiation exposure.[3] Other factors can cause cataracts, but radiation cataract severity and latency specifically are related to higher radiation dose.[3,14,15]

Evidence suggests that the current 150 mSv per year dose limit to the lens of the eye is too high and the limit is under review by an International Commission on Radiological Protection task group.[3,4,8,14,15] Ciraj-Bjelac et al indicated that the threshold for cataract development is likely lower than the current guidelines of 2 Gy to 5 Gy, and might be even less than 0.5 mGy.[3] Radiation-induced cataracts also might be more accurately described in a linear fashion and not by a threshold model.[3,14,15] Other evidence suggests that lens opacities occur within a few years at low doses (dose rates similar to those seen in the occupational setting) and that visibly disabling cataracts occur after 25 years or more.[3] Chida et al cited a study that determined 37% of the 59 interventional radiology physicians who were screened had small opacities, an early sign of cataracts.[19]

Causes of Increased Exposure

Continuous direct exposure will result in a worker exceeding his or her annual radiation dose limits quickly. Although avoiding all radiation scatter to the hands during some procedures is impossible, physicians should keep their hands as far from the primary x-ray beam as possible without negatively affecting the procedure's outcome.[5]

Shielding devices for hands are available but lack sufficient radiation protection. Disposable surgical gloves incorporate .02 mm of lead and provide a dose reduction of only 15% to 20%.[5] Efstathopoulos et al conducted research analyzing physicians who wore

8 thermoluminescent dosimeters next to their eyes, wrists, fingers, and legs during 25 interventional procedures. The physicians' left wrists received the highest radiation dose, although limits were not exceeded.[5] Because the annual dose received depends on the number of procedures performed annually, as well as the length of time required for those procedures, physicians should keep in mind that poor safety practices can lead to exceeding annual radiation dose limits.

In addition, workers might exceed radiation dose limits if they do not practice radiation protection techniques including wearing lens protection and a lead apron when stepping into a suite to monitor a procedure.[5,9,14,15] Vano et al presented a 2010 study completed in South America in which 72% of interventional cardiologists reported no use of ceiling-suspended protection screens or ocular radiation protection during the recorded procedures, and 44% reported no use of ceiling screens for previous procedures.[15] Studies have shown that the use of a table curtain can reduce doses to the lower extremities by 64%, whereas a similar dose reduction at the upper body is achievable by the use of ceiling-mounted screens.[5] For nurses, recorded doses were low (maximum dose to the extremities 41 μSv and maximum dose to the eyes 16 μSv) indicating that their position and the protective shields they used during intervention effectively reduced irradiation.[5] Protection tools should be used routinely with fluoroscopy so staff can remain below established exposure limits.

Radiation Protection Recommendations

The greatest source of secondary radiation for occupational workers is scatter radiation. One method for reducing occupational dose is to follow the as low as reasonably achievable (ALARA) principle when imaging patients.[1] Other ways are to reduce the amount of radiation time, increase the distance from the source when possible, and use lead-equivalent protection. These practices greatly reduce dose to both the patient and the worker.

Educating workers about radiation safety is essential for ensuring overall safe practice in the interventional setting. Niklason et al reported that 20% to 30% of cardiologists did not use their dosimeters routinely.[15] This failure interferes with radiation dose recordings and results in inaccurate rates of exposure to workers. Workers have the right to know their dose, and they need to keep track of the exposures they have received. Dose reports should be posted for employee review.

Wearing dosimeters correctly and at all times when using fluoroscopy is the only way dose-received data will be accurate. The monitoring device should be worn outside of clothing on the anterior surface of the body, between chest and waist level.[1] When a lead apron is worn, the dosimeter should be worn outside the apron at collar level (see **Figure**).[1] Other ways to reduce overall dose include[5,6,18]:

- Minimizing the use of fluoroscopy.
- Using collimation.
- Using appropriate positioning techniques.
- Using available patient dose reduction technology.
- Minimizing the number of acquired images.
- Using quality-assured radiation equipment.

Training programs that include initial training and regular retraining for all involved staff should be available at imaging facilities. To ensure safe operating practices, all staff members should be certified in their area and be knowledgeable about procedures and radiation use.

Shielding

Generally, 3 types of shielding are used: structural shielding, equipment-mounted shields, and personal protective devices.[4-6,18] Structural shielding is built into the ceiling, floor, walls, windows, and doors of the interventional suite and protects anyone outside the room because the scatter radiation is contained in the procedure space. Equipment-mounted shielding includes protective drapes suspended from the fluoroscopy tube or procedure table that generally contain 0.25-mm lead equivalency.[1] The table-suspended drapes reduce operator dose substantially but lose their effect when a steep oblique or lateral projection is required.[1,4-6,18]

Personal protective devices include lead equivalent aprons, thyroid shields, eyewear, and gloves. The principle radiation protective device is the wraparound lead-equivalent apron with attached thyroid shield.[1] Properly fitted aprons provide adequate radiation protection and reduce ergonomic hazards to the individual.[4-6,18] Protective aprons are to be worn at all times when fluoroscopy is used and are required to possess a minimum of 0.5-mm lead equivalent if the peak energy of the x-ray beam is 100 kV.[1]

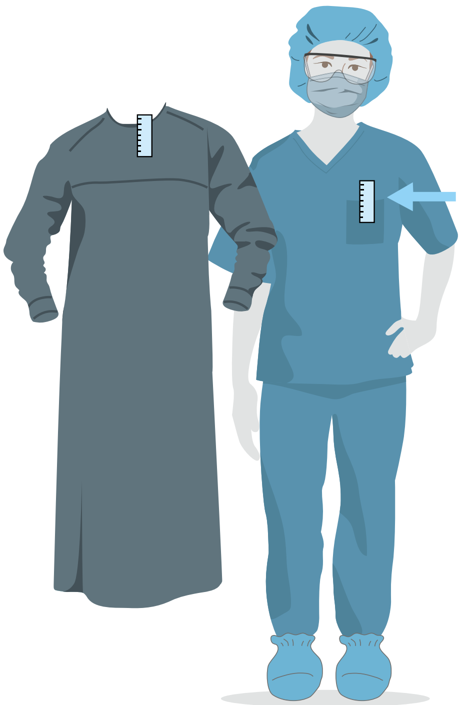

Figure. *A thermoluminescence dosimeter (TLD) badge should be worn outside of clothing on the anterior surface of the body, between the chest and waist level. When a lead apron is worn, the dosimeter should be worn outside the apron at the collar level.*

Some interventional suites have rolling and stationary shields made of lead-equivalent plastic. These, along with ceiling-suspended shields, should be used for procedures of significant length. Lightweight, sterile, disposable shields that protect the operator from scatter radiation also are available. This type of shielding device lies directly on the patient, just outside the primary x-ray beam. Simons et al conducted a study in which 40 interventional radiology procedures were performed, 20 with and 20 without sterile, disposable, radiation absorbing surgical drapes containing x-ray attenuation material. The results showed an 80% reduction in radiation dose (0.09 μSv/s with shielding vs 0.47 μSv/s without shielding, $P < .05$) to the physician performing the procedures when the drapes were used.[12] This study demonstrated that a sterile, disposable, radiation-absorbing drape provides a practical means of augmenting conventional radiation shielding.[12]

Improved Technology

Advances in technology have helped to reduce radiation dose. Today, there are a variety of built-in and manual features available on equipment that reduce the radiation dose to the patient and to surrounding workers. A majority of fluoroscopy equipment comes with settings such as low dose-rate mode, low pulse-rate option, low dose-per-frame settings for image acquisition, and low frame-rate options for image acquisition.[4] These user selection options reduce patient dose and reduce scatter to workers. Advances in image processing technology compensate for a majority of reduced image quality and reduced radiation to workers. In addition, built-in equipment configurations involve spectral beam filtration and the use of increased x-ray beam energy, which also reduces radiation to workers.[4] The fluoroscopy operator (whether this is the radiologist or technologist) might consider consulting a qualified medical physicist to gain complete understanding of the operator modes available and other equipment features.

Conclusion

Interventional radiologic procedures carry the risk of causing adverse health effects in workers because of the continuous exposure they receive from ionizing radiation. The most concerning adverse effect of radiation exposure to workers is to the lens of the eye, and this exposure is most likely to affect the interventional radiologist or cardiologist because of his or her proximity to the radiation source. However, radiologic science professionals and clinicians can protect themselves and minimize health risks associated with radiation exposure by wearing appropriate radiation protection and following the ALARA principle.

Cannon Walden, BS, R.T.(R)(VI), is a special procedures technologist for Wake Forest Baptist Medical Center in Winston-Salem, North Carolina.

References

1. Carton RR, Adler AM. *Principles of Radiographic Imaging.* 5th ed. Clifton Park, NY: Delmar, Cengage Learning; 2013.
2. Chida K, Kaga Y, Haga Y, et al. Occupational dose in interventional radiology procedures. *AJR Am J Roentgenol.* 2013;200(1):138-141. doi:10.2214/AJR.11.8455.

3. Ciraj-Bjelac O, Rehani MM, Sim KH, Liew HB, Vañó E, Kleiman NJ. Risk for radiation-induced cataract for staff in interventional cardiology: is there reason for concern? *Catheter Cardiovasc Interv.* 2010;76(6):826-834. doi:10.1002/ccd.22670.
4. Durán A, Hian SK, Miller DL, Le Heron J, Padovani R, Vañó E. Recommendations for occupational radiation protection in interventional cardiology. *Catheter Cardiovasc Interv.* 2013;82(1):29-42. doi:10.1002/ccd.24694.
5. Efstathopoulos E, Pantos I, Andreou M, et al. Occupational radiation doses to the extremities and the eyes in interventional radiology and cardiology procedures. *Br J Radiol.* 2011;84(997):70-77. doi:10.1259/bjr/83222759.
6. Kesavachandran CN, Haamann F, Nienhaus A. Radiation exposure and adverse health effects of interventional cardiology staff. *Rev Environ Contam Toxicol.* 2013;222:73-91.
7. Kim KP, Miller DL, Balter S, et al. Occupational radiation doses to operators performing cardiac catheterization procedures. *Health Phys.* 2008;94(3):211-227. doi:10.1097/01.HP.0000290614.76386.35.
8. Klein LW, Miller DL, Balter S, et al. Occupational health hazards in the interventional laboratory: time for a safer environment. *Catheter Cardiovasc Interv.* 2009;73(3):432-438. doi:10.1002/ccd.21801.
9. Papierz S, Kamiński Z, Adamowicz M, Zmyślony M. Assessment of individual dose equivalents Hp(0.07) of medical staff occupationally exposed to ionizing radiation in 2012. *Med Pr.* 2014;65(2):167-171.
10. Servomaa A, Karppinen J. The dose-area product and assessment of the occupational dose in interventional radiology. *Radiat Prot Dosimetry.* 2001;96(1-3):235-236.
11. Siiskonen T, Tapiovaara M, Kosunen A, Lehtinen M, Vartiainen E. Monte Carlo simulations of occupational radiation doses in interventional radiology. *Br J Radiol.* 2007;80(954):460-468.
12. Simons GR, Orrison WW. Use of a sterile, disposable, radiation-absorbing shield reduces occupational exposure to scatter radiation during pectoral device implantation. *Pacing Clin Electrophysiol.* 2004;27(6,Pt 1):726-729.
13. Vañó E, Gonzalez L, Fernandez J, Alfonso F, Macaya C. Occupational radiation doses in interventional cardiology: a 15-year follow-up. *Br J Radiol.* 2006;79(941);383-388.
14. Vañó E, Gonzalez L, Fernández JM, Haskal ZJ. Eye lens exposure to radiation in interventional suites: caution is warranted. *Radiology.* 2008;248(3):945-953. doi:10.1148/radiol.2482071800.
15. Vañó E, Kleiman NJ, Duran A, Rehani MM, Echeverri D, Cabrera M. Radiation cataract risk in interventional cardiology personnel. *Radiat Res.* 2010;174(4):490-495. doi:10.1667/RR2207.1.
16. Vañó E, Gonzalez L, Fernandez JM, Prieto C, Guibelalde E. Influence of patient thickness and operation modes on occupational and patient radiation doses in interventional cardiology. *Radiat Prot Dosimetry.* 2006;118(3):325-330.
17. Vañó E, González L, Guibelalde E, Fernández JM, Ten JI. Radiation exposure to medical staff in interventional and cardiac radiology. *Br J Radiol.* 1998;71(849):954-960. doi:10.1259/bjr.71.849.10195011.
18. Marx MV, Niklason L, Mauger EA. Occupational radiation exposure to interventional radiologists: a prospective study. *J Vasc Interv Radiol.* 1992;3(4):597-606.
19. Haskal ZJ, Worgul BV. Interventional radiology carries occupational risk for cataracts. *RSNA News.* 2004;14:5-6. Cited by: Chida K, Kaga Y, Haga Y, et al. Occupational dose in interventional radiology procedures. *AJR Am J Roentgenol.* 2013;200(1):138-141. doi:10.2214/AJR.11.8455.