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The Effects of Radiation Exposure in Medical Imaging to the Eye

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ABSTRACT

Since the invention of the X-ray, one of the more critical questions that has been raised is, "Does the potential harm outweigh the diagnostic benefits?" After the initial discovery of X-rays and prior to the establishment of guidelines by the scientific community in conjunction with prudent medical practices of the time, X-rays were being used by many untrained practitioners. "Cigarette cards" that were created during the late 1800s to early 1900s were known as "The Working Man's Encyclopedia" and were guides for how to use and dose X-rays to patients. Although the X-ray was promoted in both medical and commercial communities, neither one understood the short- or long-term hazards of radiation overexposure. This article will review the history of the development and use of the X-ray since its invention, discuss the hazards of radiation overexposure and lack of protective precautions, and examine all of the potential hazards and safety guidelines pertaining to radiation exposure to the eye in the field of medical imaging. Furthermore, it will discuss the measurements, devices, and regulatory guidelines that govern its use and potential harm to the operator's radiosensitive organ, the eye.

Introduction

When Wilhelm Conrad Roentgen discovered the "unknown X-ray" on November 8, 1895, he understood its potential role in medicine.[1] However, as with many inventions, the use of X-ray preceded the full understanding of its potential hazards and how to avoid these effects by implementing safe practices or standards. Initially, "cigarette cards," which were created during the late 1800s to early 1900s and referred to as "The Working Man's Encyclopedia," were guides for how to use and dose X-rays to patients.[2] Although the X-ray was promoted in both medical and commercial communities, neither one understood the short- or long-term hazards of radiation overexposure. In March 1896, Thomas Edison reported ocular complications associated with the use of X-rays and cautioned against their continued use due to these observed side effects. He decided to pursue other projects as opposed to continuing his investigation of X-rays. A factor leading to this decision was that his assistant, Clarence Dally, suffered severe X-ray burns, requiring both of his arms to be amputated. In 1904, he died as a result of his injuries, making him the first US radiation fatality.[1]

The earliest radiation protection pioneer in the United States was William Rollins, a dentist in Boston, Massachusetts. His contributions included the cryptoscope, which was a lead glass-backed fluorescent screen. In 1896, Rollins provided suggestions for protective X-ray tube housings. This practice was important in keeping "tube leakage" to a minimum. In 1902, he introduced lead glass goggles (which were a full centimeter thick) for fluoroscopists as protection against cataracts.[3] His lead goggles may have been the first attempt to provide ocular safety methods in medical imaging.

The era of the initial pioneers in radiology (1895-1915) transitioned into what is known as the "Golden Age of Radiology" (1915-1940).[3] During this time, the role of ionizing radiation evolved into a more critical role when used as a diagnostic tool in medicine. In addition, establishment of standards, guidelines, and radiation protection methods started to become a priority.[3] The medical imaging profession has come a long way since the initial discovery of the X-ray, in both safety and utilization practices. This article will discuss this journey, focusing particularly on the effects of radiation exposure to the radiologic technologist's eyes and methods for protecting this important and radiosensitive organ.

Anatomy of the Human Eye

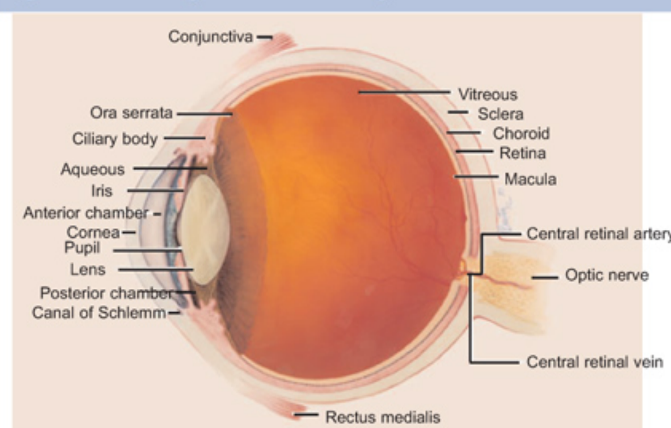
Because this article focuses on the effects of ionizing radiation to the eye, it is important to know some of the surface anatomy as well as physiology of this organ. This will also assist in understanding the potential harmful effects that can be caused by over exposure to ionizing radiation, in either the short or the long term, due to the eye's radiosensitivity.

Although small in size, the human eye is a complex organ in anatomic structure as well as physiologic function. The visual portion one can see in the mirror includes the following[4,5]:

- Iris: pigmented part of the eye
- Cornea: a clear dome over the iris
- Pupil: the black circular opening in the iris, which lets light in
- Sclera: the white wall of the eye that protects the eye from disease
- Conjunctiva: an invisible, clear layer of tissue covering the front of the eye (except the cornea)

Light passes through the pupil to the lens, which is just behind the pupil. The lens is able to change its shape and assists in the process of fine-tuning vision. Located behind the lens and in front of the retina is the vitreous, which is filled with a clear, jelly-like material known as the vitreous humour. This makes up the majority of the eye and helps hold its shape. The lens focuses the light through the vitreous humour to the back of the eyeball, which is known as the retina. Special cells in the retina known as rods and cones process the light. The retina takes the light the eye receives and changes it into nerve signals through the optic nerve so the brain can understand what the eye is seeing. Finally, in the center of the retina is the macula, which is a small region that is essential for providing sharp, clear vision (Figure 1).[4-6]

Figure 1. Anatomy of the Human Eye



Reprinted from National Eye Institute. Available at: http://www.nei.nih.gov/health/coloboma/images/eye_with_labels.jpg. Accessed May 4, 2012.[6]

Radiation Measurement Principles and Guidelines in Medical Imaging

ALARA/Medical Physicists

These days, guidelines and principles are in place to minimize the potential hazards of radiation exposure. Radiologists and radiologic technologists must follow the radiation safety principle known as ALARA (**A**s **L**ow **A**s **R**easonably **A**chievable) as they perform their diagnostic imaging studies.[3] Some basic tenets of ALARA include beam restriction (collimation/filtration), proper patient and operator shielding, prudent exposure factors, and making sure medical imaging facilities undergo regular radiation surveys and inspections. It is important to keep in mind that the principle of ALARA is important not only for patients, but for protecting the radiologic technologist.

Although each imaging department has internal personnel assigned to these tasks, such as a radiation safety officer, most imaging departments also have outside support consultants, such as a qualified medical radiation physicists (QMRPs), who work with radiologic technologists to make sure ionizing radiations are being used safely.[7] A QMRP is competent to practice independently in 1 or more of the subfields of medical physics, which include therapeutic radiological physics, diagnostic radiological physics, medical nuclear physics, and medical health physics. They are certified by the American Board of Radiology, the American Board of Medical Physics, the American Board of Health Physics, the American Board of Science in

Nuclear Medicine, or the Canadian College of Physicists in Medicine. The American Association of Physicists in Medicine regards board certification in the appropriate medical subfield as the appropriate qualification for the designation of QMRP.[8]

Radiation Measurements

The roentgen represents a unit of exposure in air and was defined as that quantity of X-rays or gamma rays required to produce a given amount of ionization (charge) in a unit mass of air. The rad was developed as a unit of absorbed energy or dose, and is applicable to any material. In the International System of Units (SI units),[9] the rad has been replaced by the gray (Gy), which is defined as 1 joule (J) of energy absorbed in each kilogram (kg) of absorbing material. Additional measurement parameters include the following: 1 Gy or Sievert (Sv) is equivalent to 100 rads, therefore 1 rad equals 10 mGy.[9]

Integral radiation dose describes the total amount of energy that is attenuated and passed into matter—in this case the medical imaging of an anatomic region through which the ionizing X-ray beam passes. For example, when a patient has a computed tomography of the abdomen, the dose per section (irradiated volume) might be 1 rad (10 mGy).

Different types of radiation, such as alpha or beta particles, produce different degrees of biologic damage as compared to gamma or X-radiation. To account for the fact that the same absorbed dose of radiation may result in different biologic responses for different types of radiation, a unit known as the radiation equivalent man (rem) was developed. The rem is the conventional unit for equivalent dose.[9]

Equivalent dose (HTR) is the product of the average-absorbed dose (DTR), in a tissue (T) due to radiation (R) and a radiation-weighting factor (w_T, previously known as the quality factor [Q]), which is specific to specific types of radiation and accounts for the biologic effectiveness of the specific radiation. The radiation-weighting factor for gamma or x-radiation equals 1. This means that 1 rad equals 1 rem for gamma or x-radiation.[9] This does not pertain to all particles, as noted in Table 1.[10]

Table 1. Q Factors for Several Types of Radiation

	X-Ray	Gamma Ray	Beta Particles	Thermal Neutrons	Fast Neutrons	Alpha Particles
rad	1	1	1	1	1	1
Q factor	1	1	1	5	10	20
rem	1	1	1	5	10	20

rem = roentgen equivalent mammal/man.
Adapted from NDT Education Resource Center. Measures relative to the biological effect of radiation exposure. Available at: http://www.ndt-ed.org/EducationResources/CommunityCollege/RadiationSafety/quan_units/units.htm. Accessed October 1, 2011.[10]

Effective dose (E) is the sum of the weighted equivalent doses for all irradiated tissues and organs. It takes into account the fact that not all tissues are equally sensitive to the effects of ionizing radiation. [9] The dose equivalent relates the absorbed dose to the biologic effect of that dose.[10]

Effective Dose (Gy) = Absorbed Dose (Gy) x w_T

Basic Radiation Protection Concepts

The 3 core concepts of radiation protection for the safety of the radiologic technologist and radiologist continue to be time, distance, and shielding.[9] An example of time would be to limit your time in the fluoroscopic suite during a procedure. This can be accomplished by making sure the radiologic technologist is not only adequately trained in the procedure that is being performed, but by developing an imaging protocol that offers maximum diagnostic information with minimal exposure. Another example would be utilizing a remote fluoroscopic system; this provides safety behind a leaded enclosure. An example of distance would be to increase your distance from the patient during a fluoroscopic examination. This is extremely important because the majority of a radiologic technologist's radiation dose comes from scattered radiation from the patient. So when a radiologic technologist assists a radiologist during a fluoroscopic procedure, he or she should be close enough to provide clinical support when required, but at a distance when they are not needed. Finally, shielding can be accomplished by using all of the various protective apparel and safety mechanisms available to the radiologic technologists with today's technologic and safety advances.

Personal Radiation Measurement Devices

One of the best ways to evaluate operator dose and improve radiation safety for any medical imaging specialist is to wear a personal monitoring device to document and record any radiation dose received. This way, if there are extensive doses, information has been gathered to determine what the cause and effect is and to help develop an action plan to make necessary corrections. Use of personal radiation monitoring devices helps evaluate the effectiveness of prudent radiation protection practices. Monthly reports received from dosimeter laboratories are official legal documents, which are reviewed. Attempts should be made to reduce any radiation exposure, no matter how small, as well as to put in place an action plan to minimize the dose or find the cause of the problem. Compliance and corrective action are key elements of a prudent monitoring plan.

Film Badges

Film badges (Figure 2) have historically been the most commonly used form of personal monitoring devices.[11] The developer of the earliest version of a film badge was Rome Vernon Wagner, who was an X-ray tube manufacturer. In 1907, at the meeting of the American Roentgen Ray Society,[12] Vernon Wagner described how he monitored his daily radiation exposure by carrying a photographic plate in his pocket and developing it each night. This early practice eventually led to the development of the film badge personal monitoring devices that are used today to calculate operator absorbed dose in medical imaging.

Figure 2. Example of a Film Badge

Image courtesy of Techno-Aide.

The film badge consists of special radiation dosimetry film packaged similar to dental film and enclosed in a special plastic holder. There are metal filters along the open portion of the badge that are usually composted of aluminum, cadmium, or cooper.[13] These metals in these filters have different atomic numbers, which help to identify the type of ionizing radiation to which an individual is exposed. When the film badge is exposed to ionizing radiation, deposits of silver atoms are distributed in the film emulsion that, upon development, become dark in proportion to the degree of radiation exposure received. The resultant optical density can be measured with a densitometer and calibrated to the degree of radiation exposure received.

Film badges are usually clipped onto the radiologic technologist's collar. In high-dose areas such as nuclear medicine laboratories and interventional suites, it is not uncommon to see individuals wearing 2 film badges—one on the collar outside of the lead apron and the other on the inside at chest or waist level. The second badge is used to determine the functionality of the lead apron. Because of the considerable controversy regarding the proper location of the film badge when a lead apron is worn, the departmental radiation safety officer should be contacted for specific guidance. The most common protocol is to wear one badge at the collar level outside the lead apron, while other protocols include a second film badge underneath the apron.

Film badges are usually issued on a monthly basis, depending on cost and long-standing client "comfort" in the technology. The film is sent to the manufacturer who provides a report showing any exposure the badges may have received. These results are reviewed by the facility radiation safety officer and/or consulting QMRP.[13]

Optically Stimulated Luminescence Dosimeters

Optically stimulated luminescence (OSL) dosimeters (Figure 3) are gradually replacing the long-used film badges.[14] OSLs work in a multi-step process. First there is an exposure to ionizing radiation. Once the OSL is exposed it utilizes aluminum oxide (most common material) as the radiation detector. The exposure causes the electrons to go into an excited state. When the OSL is sent back to the manufacturer for processing, the aluminum oxide is exposed to a laser causing these electrons to go back to ground state while emitting visible light. This emission is then quantified to determine the type and amount of dose the operator received. Some of the benefits of the OSL include its extreme sensitivity, wider dynamic range, and excellent long-term stability. However, when compared to thermoluminescent dosimeters (TLDs) and film badges, it is a more costly device.[14,15]

Figure 3. Examples of Optically Stimulated Luminescence Dosimeters

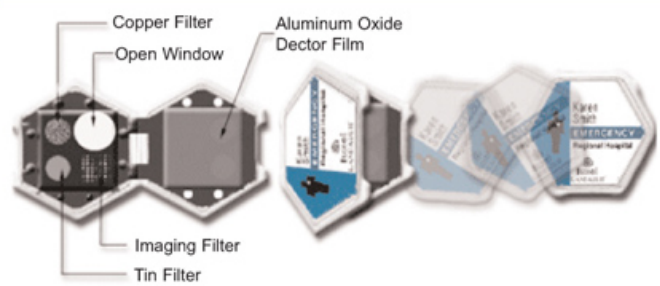


Image courtesy of Landauer.

Thermoluminescent Dosimeters

Thermoluminescent dosimeters (TLDs; Figure 4) are similar in appearance to film badges. Instead of using film to measure the radiation exposure, TLDs use a phosphor such as lithium fluoride (LiF) or calcium sulphate crystals laced with magnesium, titanium, copper, or phosphorus impurities.[16,17] When exposed to radiation (X-ray), a portion of the absorbed energy is stored in the crystal structure of the LiF chips in metastable states. This absorbed energy will remain in these states for long periods of time. When the TLD is returned to the manufacturer, they expose it to heat and the absorbed energy is released as visible light. The amount of light emitted is then measured and a dose factor is calibrated. The heating and measurement of the LiF chips are carried out in a device called a reader, and the amount of measured light is proportional to the absorbed radiation dose.[17]

Figure 4. Example of a Thermoluminescent Dosimeter

Reprinted from National Institute of Standards and Technology. Available at: http://www.nist.gov/pml/div682/grp02/images/NIST-Work-in-Support-of-the-Navy-Dosimetry-Program_1.jpg. Accessed May 11, 2012.[16]

Thermoluminescent dosimeters provide approximately the same measurement range as film badges and can be used as whole-body badges or collar badges. Because of their small size, TLDs can be ordered in the form of a ring badge. A ring badge, which is a type of TLD, can be used to determine extremity doses in high exposure areas such as nuclear medicine, cardiac, and interventional specialty imaging suites.

Benefits of TLDs include being more accurate, reliable, and sensitive than film badges and pocket dosimeters. Their response to low and high energy photons is more uniform, and they can be calibrated to be sensitive to a particular type of radiation. A final advantage of film badges is the long-term proven archive ability of the used film. The primary disadvantage of TLD monitors is cost. The monitoring program can be twice as expensive as film badge monitoring.

Pocket Dosimeters

A special type of ionization chamber used for personal dosimetry is known as a pocket dosimeter (Figure 5). Pocket dosimeters are used when there is the potential that an operator will be exposed to high amounts of radiation in a short period of time and needs to see the dose instantly. An example of when this might occur would be when performing interventional or cardiac procedures. When irradiated, the radiation ionizes the air in the chamber, which partially neutralizes a previously positively charged electrode (a quartz fiber on a wire frame), causing the electrode to move on an exposure scale. The amount of ionization and movement of the electrode is proportional to the radiation exposure to the chamber. The pocket dosimeter also requires a charger (Figure 6), which is a transistor power supply that "zeros" out all direct-reading dosimeters.

Figure 5. Example of a Pocket Dosimeter

Figure 6. Example of a Pocket Dosimeter Charger

Image courtesy of Supertech, Inc.

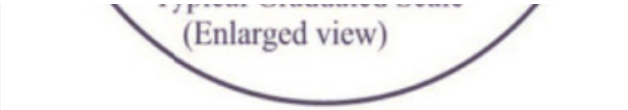


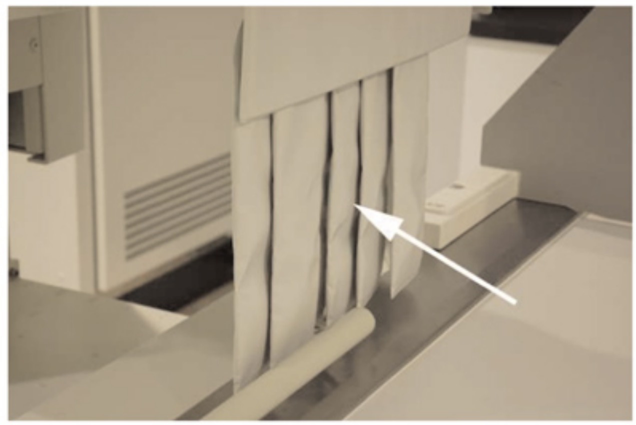
Image courtesy of Supertech, Inc.

Another example of when a pocket dosimeter would be beneficial is if a nonmedical or medical personnel has to hold a patient and be near the primary X-ray beam. Wearing the pocket dosimeter, as well as putting other protective measures in place, can minimize the potential radiation exposure. The main disadvantage of pocket dosimeters is that it does not provide a permanent record of personnel exposure. Dose received would need to be manually documented in a compliance log book, a key point on why pocket dosimeters are not routinely used.

Fluoroscopic Procedures

Cinefluoroscopy ("real time") produces more of a risk of ocular exposure to the operator than any other specialty area.[18] The nature of fluoroscopic imaging is a continuous or pulse beam of ionizing radiation. Fluoroscopic applications include the subspecialties of cardiac and interventional studies. Managing fluoroscopic safety requires several elements, including equipment performance evaluation, quality control testing, monitoring of radiation dose to the patient and operator, and proper training of the support medical staff who may be involved with some of the specialty procedures. An additional major concern is that many nonradiologists use fluoroscopy to perform procedures within the scope of their clinical specialty (ie, orthopedics, pain management, neurology, cardiology) but may lack the training radiation safety and X-ray physics.

Figure 7. Protective Curtain on the Control Tower of a Fluoroscopic Unit



Reprinted with permission from Online Digital Imaging Academy (ODIA). Module 8: ALARA. Available at: https://www.asrt.org/Applications/ODIA/ODIALogin.aspx. Accessed October 4, 2011.[11]

The first step to minimizing ocular exposure to the operator is to use the protective curtain (lead drapes) that are usually attached to the control tower component of the fluoroscopy unit. Most fluoroscopy systems contain side-table drapes (Figure 7) or similar types of lead shielding.[11] The protective curtains found on fluoroscopy machines usually are 0.25-mm lead equivalent in thickness. Radiation dose levels at the eye or thyroid level are greatly reduced from 2 to 5 mGy/h (20-50 mrem/h) without a lead drape to 1 mSv/h (0.1 mrem/h) with a lead drape.[18]

The Bucky slot cover is an additional form of shielding, which also is found on the fluoroscopy machine. The Bucky slot cover is at least 0.25-mm lead equivalent thick. It covers the opening underneath the fluoroscopy table that is left vacant when the film tray and Bucky assembly are moved out of the way for the procedure. If this gap was not filled, the radiologist and radiologic technologist would receive a high dose of radiation because the X-ray tube is located beneath the table on most fluoroscopic equipment.

Fluoroscopic units must have an audible timer that sounds every 5 minutes to remind the user of the time passing. This is a federal law in the United States that benefits the patient, along with everyone else in the room. The fluoroscopic beam should only be in an "on" mode when the procedure is being performed, and even then, only when viewing clinically valuable information that will lead to completing the examination and patient diagnosis.

A list of recommendations to minimize fluoroscopic exposure to the eye is provided in Table 2.[19-21] Suggestions include use of proper collimation techniques and settings, additional protective gear such as lead aprons, hoods (Figure 8), and glasses, and providing the appropriate training to ensure the process is efficient.

Table 2. Fluoroscopic Safety Recommendations

Figure 8. Leaded Hood Guard

- Always collimate tightly on all 4 corners of the image. Tight collimation lowers scatter dose, as well as improves image quality through better contrast levels.
- Use pulse mode as opposed to continuous beam fluoroscopy.
- Make sure not to expose your back to the fluoroscopic beam; if it is necessary, be sure to wear a "wrap around" type lead apron or vest.
- Lead aprons should be tested for defects before being used. The Joint Commission on Accreditation of Health Organizations requires annual testing for lead protective apparel shielding integrity, as well as initial testing upon acceptance/purchase.
- Smaller image intensifier settings and magnification mode tend to increase patient dose to a small area. The magnification mode should only be used when clinically necessary.
- Wear lead glasses and a thyroid collar to supplement standard radiation protection apparel.
- The image intensifier should be kept as close to the patient as clinically prudent; this, in turn, curbs the fluoroscopic beam intensity, maintaining it at a low level.
- Scatter radiation from an operator's head can affect ocular exposure. Use of new leaded hoods can assist with dose decrease.
- The department QMRP should look into various personal monitoring devices that can be worn during fluoroscopy to calculate the final dose factors that are obtained.
- Other effective lead shield options to help reduce radiation exposure during the course of long interventional or cardiac procedures include the use of ceiling-mounted lead acrylic full-face shields, table side drapes, and/or mobile door-shaped shields.
- Utilize mobile secondary barriers to provide radiation protection inside the examination room for medical personnel who are not required to be in the room for a specific part of an examination but may need to be called if an emergency occurs.
- Use virtual educational technique and simulators prior to performing a new type of procedure to make sure you are familiar with proper technique, anatomy, and pathology.

Data from Coons[19]; Brateman[20]; and Limacher et al.[21]

Image courtesy of Techno-Aide.

Radiation Effects on the Eye

Types of Cataracts

The main effect of radiation on the eye is the development of cataracts. There are several different types of cataracts: nuclear, cortical, and posterior subcapsular.

Cataracts that affect the center of the lens are known as nuclear cataracts. The first noticeable changes from this type of cataract are usually nearsightedness or experiencing a temporary improvement in reading vision. However, with time, the lens gradually turns more densely yellow and vision becomes further clouded. Nuclear cataracts sometimes cause double vision or even multiple images. As the cataract disease process progresses, the lens may even depict a brown color. Advanced yellowing or browning of the lens can lead to difficulty distinguishing between shades of color.[22]

Cortical cataracts start at the outer portion of the lens and then slowly move inward. As the disease progresses, the streaks extend to the center and interfere with the passing of light through the center of the lens. This type of cataract is more prevalent in patients with diabetes. Problems with glare are common for this type of cataract.[22]

Cataracts that affect the back of the lens are known as posterior subcapsular cataracts. This type of cataract is usually seen in patients who suffer from diabetes, extreme nearsightedness or retinitus pigmentosa, or who take steroid medication. A subcapsular cataract often interferes with reading vision or reduces vision in bright light, causing glare or halos around lights at night.[22]

Radiation-Induced Cataracts

The first radiation-induced cataracts were reported in 1949 and by the 1960s, several hundred cases were reported.[13] It is thought they were caused by the use of cyclotrons, which are devices used to accelerate charged particles to very high energies. Cyclotrons were initially used in research and academic settings in the early 1930s for research, educational, and teaching purposes. Using cyclotrons allowed the physicists to look directly into the beam, leading to high doses of radiation to the eyes' lenses. Physicists who worked with cyclotrons used radiographic intensifying screens to help locate the high-energy beam. Radiation-induced cataracts that developed from this type of exposure were in the posterior pole of the lens. Through evaluation of these cases, several conclusions were reached about radiation-induced cataracts[13]:

- Radiosensitivity of the eyes is dependent upon the individual's age.
- The effect of the radiation is greater on older individuals.
- The average latent period is 15 years, whereas the shorter latent period ranges from 5 to 30 years.
- For the formation of cataracts, high low-energy transfer radiation has high relative biologic effectiveness.

The severity of the biologic effects from radiation exposure is based on the absorbed dose and the extent of the body area exposed. Biologic effects are divided into deterministic and stochastic effects. An example of a deterministic effect would be the development of cataracts. Stochastic effects include cancer and genetic risk. The potential to develop a cataract depends on the absorbed dose and rate of dose accumulation. If given in a single include cancer and genetic risk. The potential to develop a cataract depends on the absorbed dose and rate of dose accumulation. If given in a single dose, the minimum amount associated with the development of a progressive cataract is approximately 200 rads.[23]

Recommendations for Protection to the Eye for Radiation Exposure in Medical Imaging

Radiologic eyeglasses (lead-coated eyeware) are the main method for shielding the ocular lens to some degree from the harmful effects of prolonged X-ray exposure, effectively scattering X-rays that may cause eyesight dysfunction or damage in the future. This type of specialty leaded eyeware can be designed for nonprescription or prescription corrective lenses, including single vision, lined, and non-lined bifocal glasses as well. Leaded glasses should have a lead equivalent of 0.75-mm lead to ensure satisfactory protection from exposure. Taking the precaution of using leaded eye ware can reduce the amount of scatter radiation that reaches the radiosensitive lens of the eye to less than 4%.[24]

For medical imaging professionals who work with a modality that potentially exposes the lens of the eye to radiation every day, it is important that when they visit the ophthalmologist, a thorough examination of their eyes is performed. This would include looking at the lens through a slit lamp device. In 2004, the Radiological Society of North America released a report on the occupational risk for cataracts in interventional radiology. Anna Junk, MD, a lead author and ophthalmologist at Albert Einstein College of Medicine, stated, "One of the most important findings was that the changes observed were found in interventional radiologists in their mid-40s. Even though these small opacities will not yet interfere with the ability to work, they have to be taken seriously because they reflect radiation exposures dating back 10 or more years."[25] With this in mind, one potential change is to start performing yearly extensive ophthalmologic examinations earlier for radiologists and cardiologist who perform long fluoroscopic procedures.

Regulatory Guidelines, Compliance, and Dose Parameters

The protective umbrella of compliance and laws governing exposure and protection in the medical imaging environment includes many agencies from federal, state, and even at times local levels. This leads to overlap and the need to make sure one *is* compliant.

The US Center for Devices and Radiological Health is a part of the US Food and Drug Administration. They set standards for commercial manufacturer's new equipment guidelines and radiopharmaceutical development, but do not govern occupational exposure guidelines for the operators of this equipment. This falls under the role of the Nuclear Regulatory Commission (NRC), who is responsible for regulating the production of radioactive materials, as well as the safety of the workers exposed to them. Furthermore, states have the right to regulate all sources of radioactive materials, including X-ray tubes. They have an arrangement with the NRC to regulate medical licensing and inspection requirements of radioactive material, which includes Title 10, Code of Federal Regulations, Parts 20 (the standards for protection against radiation).[13] All of these regulatory agencies are guided by policies and input from the National Council on Radiation Protection and Measurements (NCRP), the International Commission on Radiation Protection, the International Atomic Energy Agency, the Joint Commission on Accreditation of Healthcare Organizations, and the American College of Radiology.

The NRCP lists other limits for occupational exposure, which are based on their recommendations, specifically NRCP Report No. 116. This report outlines the basics of radiation protection, including the following limits[26]:

- Whole body dose for occupational exposure is 5 rem
- Limit for the lens of the eye is 15 rem
- Limit for the hands is 50 rem

In addition, professional organizations and subcommittees are forming with both interventional radiologists and cardiologists to determine future topics and solutions to radiation exposure.[27] It is extremely important that all of these groups gather and share both statistical data and reports from their memberships on exposure and risk management, as well as compliance, to improve radiation safety practices.

Figure 9. Zero Gravity Radiation Protection System

Two key components are the protective lead outfit that is held and lowered by the articulating arm, displayed here.
Image courtesy of CFI Medical Solutions, www.cfimedical.com

New Radiation Safety Technology for Medical Imaging

Overhead Radiation Protective Suits

Concerns about how to decrease radiation dose to the operator have spurred a new generation of protective apparel. The age-old question has always been, "How can you provide maximum radiation protection to the operator of fluoroscopic equipment during long interventional procedures without 'weighing' them down with the heavy leaded protective equipment?" One new device that is available commercially is the ZeroGravity Radiation Protection System suit (Figure 9), which offers a new and unique radiation protection suit with an overhead adjoining apparatus.[28] It has a base that allows the vest to move around, or the system can be mounted to the ceiling on rails. The other component is a suit made of a magnetic airware vest and sterile gown; once the radiologic technologist puts it on, the suit attaches to the base. The thickness of the lead apron is 1 mm, which is twice the thickness of the usual standard for lead aprons.[28] In addition, this system offers front and side protection. The ceiling suspended leaded shields are effective in reducing the lens dose rate due to the full coverage provided around the face region. This is a radiation protection system designed for high volume cardiac, electrophysiology, and interventional fluoroscopic imaging laboratories.

Pocket-Type Dosimeters

There is new generation of small pocket dosimeters that can be integrated via a USB connection to a computer so that an individual's radiation dose can be viewed and documented using the products software program (Figure 10). These products couple state-of-the-art memory chip technology with proprietary software to not only view radiation dose, but keep an updated online record.[29]

Figure 10. Example of Small Pocket Dosimeter

Image courtesy of RC Imaging.

Protective Sterile Leaded Drapes

Disposable protective sterile drapes for interventional procedures are now commercially available. These drapes contain metallic elements such as bismuth or tungsten-antimony. The disposable shield is designed for various interventional examinations and specialties (Figure 11). Some studies have shown a scatter reduction using these types of drapes as high as 12-fold to the lens of the eye.[30] Though they increase the overall cost of the procedure, the decrease in radiation dose due to scatter limitations for the operator are well worth the cost.

Forthcoming Changes in Medical Imaging Equipment and Compliance

Continued efforts to reduce radiation dose to the patient and operator are usually dictated by changes in compliance. One such change may be coming in the form of the Consumer Assurance of Radiologic Excellence (CARE; HR 2104) bill.[31] This bill assures that professionals who perform radiologic procedures are properly qualified. There are also clauses that address repeat radiographs and the resulting increase in patient radiation dose. As of December 2011, at the end of the first session of the 112th Congress, there were 67 bipartisan cosponsors of the CARE bill and this bill has been referred to the House Subcommittee on Health.[31]

Figure 11. Protective Sterile Lead Drape Example

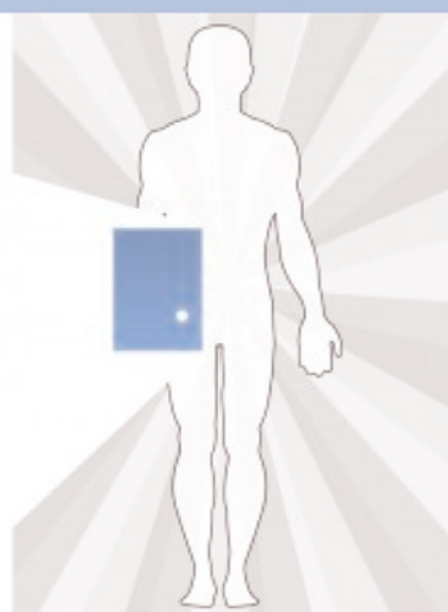


Image courtesy of RC Imaging.

Another way to address future compliance is with proper dose documentation. This has included integration of the radiographic/fluoroscopic generator to the digital capture device to document exposure techniques. Others are starting to use dose area product (DAP) meters that can be attached to their collimators.[32,33] A DAP meter is an ionization chamber with associated electronics that can measure patient dose during a procedure. Though there are some ongoing debates about the measurement standards and parameters that need to be taken into account when using a DAP meter, most will agree that some degree of patient dose measurement is better than none.

Conclusions

The use of ionizing radiation in medicine and implementation of practice guidelines to reduce radiation dose to patients and operators has come a long way from the early 1900s. Today, there are solid guidelines for radiologic technologists to follow and protective gear to help monitor radiation exposure. There are also certified professionals available to help ensure compliance with regulated safety standards. As we strive for continued improvement, the future may hold more devices to ensure continual and increased safety, as well as documentation of even minimal amounts of patient or operator dose, hopefully making radiation-induced cataracts a disease of the past.

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Comments/Questions

What did you think of this article?

The Effects of Radiation Exposure in Medical Imaging to the Eye

» **Comment From: davehall** » *Posted on: 06/13/2012 17:01 PM*

Good article, well organized and information that, although not new, is still relevant to all of us working around ionizing radiation.

» **Comment From: Sue Kelley** » *Posted on: 06/14/2012 16:40 PM*

Question 12 doesn't have a clear answer. Nuclear is not listed as a type. Two of the choices aren't discussed.

» **Comment From: duncan** » *Posted on: 06/20/2012 14:28 PM*

Good to see someone else had trouble with question 12. Even the internet didn't have either "subretinal" or "pigmented" as types of cataracts. Otherwise, good article.

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