RADIATION EXPOSURE TO PHYSICIANS HANDS

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Chronic irradiation of the hands is a principal radiation safety concern of all physicians involved in the broad spectrum of high dose fluoroscopically guided interventional procedures developed during the past 20 years.[1] Of particular concern are interventional radiologists, pain service physicians and GI physicians who, during certain procedures, receive some of the highest radiation doses of any medical personnel.

In terms of risk to medical personnel, fluoroscopically guided interventional procedures differ from other forms of radiation in one very important way. Physicians or other medical personnel cannot move behind a shield. He or she has to be in the room when X-ray exposure occurs. Furthermore, because of the manipulation required in these procedures, the physician's hands must be in close proximity to the scanning plane. In fact, despite the increased use of devices such as needle holders, which are designed to reduce exposure to the hands, many of these procedures are quite complex and force the physician to place his or her hands directly in the radiation beam for a limited amount of time. Even when direct exposure can be avoided, the level of exposure due to scatter can be extremely high during interventional procedures.[2]

It is no surprise then, that radiation exposure to hands is frequently the most significant factor in terms of overall radiation risk for physicians performing these increasingly common interventional procedures. More surprising, perhaps is that as noted below, hands are the part of the body for which interventional radiologists are least likely to use protective garments.[4]

Accumulated radiation exposure to hands not only places physicians at risk for injury, it also, if reported, becomes one of the biggest limiting factors on the number of fluoroscopically guided interventional procedures physicians can safely do within a given time period.[3] "It should be remembered that radiation exposure is cumulative over one's lifetime and that the effects are permanent", says Evan C. Lipsitz, MD, Assistant Professor of Surgery, Montefiore Medical Center, Division of Vascular Surgery. He adds, "reducing fluoroscopy time, increasing distance from the source and using adequate protection with monitoring are the most basic ways of reducing exposure and can significantly reduce exposure in all settings."

Categories of Radiation in Medicine

There are three broad categories of radiation in medicine today. The most intense in terms of radiation exposure to the patient is radiation therapy, in which a tumoricidal dosage is highly focused on neoplastic tissues in an attempt to cure or control local disease. Patients undergoing radiation therapy naturally receive the highest doses of radiation exposure, although all efforts are made to minimize the potential for adverse reactions in the surrounding healthy tissue. The second category is diagnostic radiology. The third category encompasses the high dose fluoroscopically guided interventional procedures such as angioplasty and stent placement. Interventional procedures typically involve a single dose fraction of low-energy X-rays with limited variation in the direction of applications. Patients undergoing fluoroscopically guided interventional procedures absorb considerably larger doses from ionizing radiation than patients undergoing diagnostic procedures. Some clinicians believe the high doses reported in the interventional literature actually under-represent the exposure for many long, complex individual cases.5

Sources of Radiation

Primary radiation refers to the radiation beam used for diagnosis or treatment and often called the useful beam. Secondary radiation is made up of leakage radiation, which comes from the X-ray tube housing assembly, and/or scatter radiation. Scatter results when the useful beam intercepts an object so that some X-rays pass through while others are dispersed thus making the scattering object a new "source" of radiation. During medical procedures, the patient is the single most important scattering object. The degree of scatter increases with increasing tissue density. As a general rule of thumb, the intensity of a scatter radiation 3.3 feet from the patient is .1 percent of the intensity of the useful beam at the patient.6

Potential Biological Effects Following High X-ray Dose Interventional Procedures

The biological effects of radiation frequently are separated into two categories. Deterministic effects, such as erythema or cataract, are those for which a minimum number of cells must be affected above a threshold dose before the biological response is observed. As the dose increases above the threshold, the likelihood of observing the effect and the severity of the effect increase. If the dose is sufficient, there is a 100 percent certainty the effect will be induced.7

But many radiation induced effects occur when change in a single cell is sufficient to initiate biological processes such as the development of cancer. These effects are called stochastic and there is no known threshold dose. The likelihood of inducing the effect but not the severity increases with dose and may differ among individuals. Such radiation risks include cancers of the blood, bone, lung, parotid gland and other organs, including the skin.

The first cancer thought to be caused by exposure to X-rays was a skin cancer case diagnosed in 1902, seven years after Roentgen's discovery. Early radiologists were unaware of the risks associated with X-ray exposure and many individuals accumulated very high radiation doses in a short time.[7]

If fluoroscopic doses are sufficiently high to include deterministic effects, skin effects are one of the earliest and most frequently observed and are usually of principal concern. Skin exposed to ultraviolet radiation is more sensitive to X-rays. This is because fluoroscopic X-rays are attenuated rapidly in tissue. The dose is maximized at the point where the radiation beam enters the skin. The skin is also rendered susceptible to radiation effects because basal cells of the epidermis are rapidly dividing stem cell populations, which are typically more sensitive to radiation than mature cells. The most common forms of cancer on the hands and arms are squamous cell carcinomas, while basal cell carcinomas are more likely to occur on the head and neck. Radiogenic skin cancer is frequently associated with chronic radiation dermatitis, sometimes only observable at the microscopic level. When associated with recognizable chronic dermatitis, the skin cancer may be more aggressive.

Depending on the specific effect, the latent period may vary from minutes to decades. Erythema will generally be present and reach its peak between one and three weeks after exposure. Because the signs of acute radiodermatitis clear spontaneously, cases with mild symptoms may go unrecognized and long-term consequences of radiation overexposure appear months to years later.[8] Radiation and leukemia generally develop 10-15 years after exposure but may occur as early as 2 years or as late as 25. The latent period for radiogenic skin cancer ranges from 4 to more than 40 years, with squamous cell and basal cell carcinomas, the principally associated types of cancer.

Beginning of Regulation for Radiation Exposure

In 1992, likely reflecting the sharp rise in the number of procedures being performed, the Food and Drug Administration (FDA) began receiving reports of radiation-induced injuries to the skin of patients who had undergone extensive fluoroscopically guided interventional procedures. Injuries ranged in severity from erythema to tissue necrosis requiring skin grafting. The injuries occurred after a variety of interventional procedures including cardiac catheter ablation, catheter placement for chemotherapy, transjugular intrahepatic portosystemic shunt placement, coronary angioplasty, renal angioplasty, multiple hepatic or biliary procedures like angioplasty, stent placement and biopsy, and percutaneous cholangiography followed by multiple embolization procedures.[9,5]

Monitoring

Monitoring radiation is a primary goal of all institutions. According to Bruce[15], the FDA's radiation concerns may lead to dose displays for fluoroscopy units but in terms of monitoring physician exposure, the burden falls on the physician and other medical personnel to wear monitors and the institution for having a program in place to determine the amount of radiation accumulated. The use of radiation badges or dosimeters by all persons working with fluoroscopy is mandatory and required by law. One badge is to be worn at waist level under the lead apron, with an additional badge to be worn on the collar to monitor the head dose and aid in calculating the total effective dose[4]. If only one badge is available it should be worn at the collar. Monitoring of hands and all body positions at risk is essential. According to Dr. Lipsitz[4], the dominant hand finger doses have not been shown to correlate with doses estimated by shoulder badges therefore ring badges or dosimeters worn on the dominant hand are considered highly advisable but are not mandatory unless made so by the individual institution.

Monitoring for physicians is both a short- and long-term process. Theoretically, at least, physicians should calculate the exposure incurred in the various procedures they perform and thereby determine the number of procedures he or she can perform in a year, based on the cumulative occupational dose limits as determined by the ICRP[16]. For example, Silverman et al.[3] concluded that personnel using CT fluoroscopy to guide abdominal biopsy procedures and catheter drainage of ten received high radiation exposures, estimated at 10 cm for the hand and 100 cm for the neck or body, comparable with the personnel exposures reported during cardiac catheterization. Exposure to hands was the most significant factor in terms of total accumulative risk. At a maximum permissible dose of 5 rem to the body per year, 481 procedures would be allowed. At a maximum permissible dose of 50 rem to the hands per year, only 164 CT fluoroscopic procedures would be permitted.

Many physicians use the pre-determined radiation levels assigned to specific procedures as a way to estimate their own radiation exposure. But monitoring personnel exposure is considerably more accurate and of much greater importance, according to a study by Vehmas[16], because of the wide differences in radiation exposure to medical personnel based on complexity of the procedures they perform. Like many others, Vehmas found that interventional procedures are associated with high radiation doses, both to staff and patients. In a study of 28 American interventional radiologists done by Niklason[1], the annual effective dose was found to be 3.16 mSv. Vehmas[16] quotes this study but argues that actual dosage may be much higher depending on the complexity of cases seen by individual physicians. By dividing as series of interventional drainage cases into standard ones requiring only a single successful catheter insertion and complex procedures requiring two or more interventions in the same session or interventions that failed or had problems, the authors found that screening times varied widely. In fact, the median value of several parameters correlating with exposure in complex procedures was roughly double than those of standard procedures. They concluded, "real radiation exposure during certain kind of radiation work may be considerably higher than most publications admit."

Pulsed Fluoroscopy

Radiation producing equipment and techniques for its use are continually being modified and improved. An ongoing goal is to reduce exposure, sue to stray radiation, by tightening the beam. The use of pulsed fluoroscopy can reduce exposure by effectively "reducing on-time". Holmes et al. demonstrated a 37 percent reduction in radiation exposure for physicians using pulsed fluoroscopy compared with conventional systems.[17] The actual amount of reduction is dependent on the specific pulse settings.

Protective Shields

Shielding was one of the earliest and is still one of the most effective protections against radiation exposure. Protective apparel is particularly important during mobile C-arm fluoroscopy or portable radiography because the control console is not positioned behind fixed protective barriers as it is for fixed units during diagnostic radiographic procedures. When using fixed units personnel may leave the room while screening runs are obtained. Drapes and aprons made of lead impregnated vinyl are usually the primary protective barriers against stray radiation. If well paced, these drapes provide medical personnel some additional protection by reducing radiation scatter.[13] Tin is used in some garments because it has some advantages over lead as a shielding material.

Devices

Since keeping hands out of the beam is a primary goal during interventional procedures, devices that allow physicians to perform manipulations outside the beam are significant. Kato et al[18] describe the development in 1993 of CT fluoroscopy, allowing the radiologist to guide the biopsy needle while observing puncturing direction and wrote in real time on a display screen. The result was simplified and more accurate biopsies can be performed in any region of the body. However the price to be paid, like so much in the history of radiation advances, was the exposure of the physicians' hands to X-rays during the manipulation of the interventional needles.

If the physician's hand is exposed to direct beam the mean dose reaches 120 mSv per procedure. Thus on the basis of the annual dose limit of 500 mSv for the hands as set by ICRP, a physician could only perform four CT fluoroscopy-guided procedures per year and remain within occupational exposure limits. Kato[18] found that with a biopsy needle holder, allowing the physician to place his/her hands 4 cm from the direct beam, the exposure would drop to 1.5 mSv per procedure. This reduction would enable the physician to perform 330 procedures a year. However, as Nawfel[18,13] reports, the needle can become dislodged, require additional force or seek maximum tactile feedback, the physician puts his or hands in the beam.

GLOVES

Radiation-attenuating flexible gloves are available as a substitute for standard gloves in situations in which medical personnel are likely to be exposed to radiation during fluoroscopic procedures. The gloves are made from materials that contain elements with atomic numbers large enough to attenuate x-rays.[19]

In assessing the effectiveness of radiation attenuating gloves, Wagner and Mulhern[19] believe is it necessary to include protection from both forwards-scattered and back-scattered x-rays as well as secondary electrons. They conclude that (some) gloves provide a modest amount of net protection, but physicians must always remember that protection is moderate at best, that the image of the hand inside the glove exaggerates the actual protection, and that they should not be lured into a false sense of security regarding placement of hands in the direct beam. Radiologists should refrain from placing hands in the direct beam, and if possible, work on the exit-beam side of the patient. Leading medical experts believe that reducing radiation exposure to the physician's hands will also reduce exposure to the patient, as well as the total body exposure of the operator. Conversely, by reducing exposure to the patient or total effective dose to the operator, should reduce exposure to the hands except in the setting where the hands, as previously noted, may be placed directly in the beam.

Continuing advances in glove technology may change the reluctance of physicians to embrace radiation-attenuating gloves, as may increased concern about radiation risks or new legislation. In Germany, regulations expected to become effective in early 2002, will require all healthcare professionals to *wear gloves intended to reduce exposure to scattered and secondary radiation.* Such legislation changes in the United States would do more to encourage the purchase of gloves, but based on compliance data about gloves and other protective items given below, assuring their usage would require a strong educational approach.

COMPLIANCE

Although interventionalists are aware of and concerned about the risks to their health, any focus first and foremost on the patient and the task at hand, second on the impact cumulative exposure (or at least reported cumulative exposure) has on their ability to continue to do procedures during a time period, and only last on their own protection.

Reviewing a study by Marx et al. in which nearly half the respondents rarely or never wore their (mandatory) radiation badges, 73 percent rarely or never wore lead glasses, 70 percent rarely or never used a ceiling mounted lead shield, and 83 percent rarely or never wore gloves, Lipsitz concluded that "there can be significant complacency even among the population of physicians who are at the most risk and who have had substantial training in radiation safety and physics."[4]

Niklason et al.[1], found that 43 percent of interventional radiologists rarely or never wore the radiation dosimeter issued to them at their institution. The reasons for lack of compliance are not known. One possibility is the lack of risk information provided by current dosimeters. Radiologists provided with doses from one of more dosimeters would have difficulty converting dose to risk. Another possible reason for lack of compliance is that interventional radiologists may occasionally exceed current radiation limits. In Niklason's study, five of 30 participants indicated they had exceeded monthly or quarterly limits – a very high percentage considering that fewer than half of the participants always wore dosimeters.[1]

Because of safety concerns, leading medical experts believe physicians who perform interventional procedures with fluoroscopy should learn more about the facts that effect radiation exposure – and follow several basic tenets: reduce fluoroscopy time, increase distance form the source and use adequate protection with monitoring. To date, neither the FDA nor the Occupational Safety and Health Administration (OSHA) mandate radiation attenuation protection for healthcare professionals. Until such regulations are in place, it is imperative to provide all healthcare professionals with information and education, especially as it relates to hand injuries resulting from exposure to scattered and secondary radiation.

In 1994, as injury reports continued to come in, the FDA decided that many physicians performing these procedures may not appreciate the magnitude of the skin doses that can result from these long, complex interventional procedures. A public health advisory was issued to alert the radiologic community to this concern and to suggest actions that might be taken to reduce the potential for radiation induced skin injuries to patients. These actions included establishing standard protocols for screening, monitoring radiation dose rates, as well as modifying protocols when necessary and recording information on exposure. It followed this up with a 1995 recommendation that the facility record in the patient's record information about the absorbed dose to the skin for any procedure with the potential for a skin dose approaching or exceeding a threshold to be set by the facility. The FDA suggested a threshold of 1Gy. In addition to the aforementioned procedures, the FDA also added procedures with the potential for long exposure time including cardiac catheter ablation, vascular embolization and percutaneous endovascular reconstruction.[5]

Dose Limits

The International Commission on Radiological Protection (ICRP) sets effective radiation dose limits. Effective dose is a concept proposed by the ICRP to relate the risk from partial-body radiation dose to that from an equivalent whole-body dose. The ICRP suggests that approximately 37 percent of the total skin surface not shielded by the lead apron is present in the arms, lower legs, hands and feet, with skin of the hands and forearms likely to receive a higher radiation dose than the skin areas measured by the dosimeter placed over the collar of the lead apron. Dose limits to adult occupational works are:

- 2000 millirem (20 mSv) per year averaged over a five-year period, not to exceed 5000 millirem or 50 mSv in any one year.[10]
- 15,000 millirem (150 mSv) per year to the lens of the eye.[11]
- 50,000 millirem (500 mSv) per year to the skin or to any extremities (hands and forearms, or feet and ankles).[11]

Exposure to Physicians' Hands

Chronic irradiation of physician's hands is a principal radiation safety concern for interventionalists. Tissue damage is generally considered more important than the risk of skin cancer. Radiation injury to the skin usually manifests as acute or chronic radiation dermatitis. Chronic dermatitis frequently occurs years after the irradiation exposure, sometimes without preceding acute changes. The threshold dose for dermal necrosis and telangiectasia subsequent to protracted irradiation is about 30 Gy. Limiting annual hand exposure to less than 0.5 Gy should be adequate to prevent such effects.

Because radiologists routinely work with their hands close to the X-ray beam, the hand receives doses that are considerably higher than doses received by the total body. According to Nawfel CT fluoroscopy provides physicians with immediate feedback of images during interventional procedures this is because the images are reconstructed and displayed in real time. However, unlike conventional CT, CT fluoroscopy requires personnel to be in the procedure room while X-ray exposure occurs. During the procedure, the patient is exposed to radiation at or near the needle puncture site.

In a study by Anderson[14] of 45 interventional radiology procedures, the fingers received a 31 percent lower dose than the palm of the hand, most likely due to hand position when maneuvering. Also the left hand received 28 percent greater dose than the right hand, due to the way in which the radiologist is positioned in comparison to the patient. The left hand finger doses ranged from a minimum of .01 mGy to 11.40 and the right hand finger doses from 1.08 to 4.62. The standard deviation is high because of the variability of the different procedures performed, the difficulties that may be encountered, and the affect of the physician's experience on total procedure time. The authors conclude that the doses recorded on the ring badges of radiologists probably underestimate the maximum exposure by approximately 30 percent.

Safety Practices to Reduce Physician Radiation Exposure

For almost a century now, the medical profession has taken numerous steps to protect patients and medical personnel from the risks of radiation. Most steps follow the same three cardinal principles of radiation protection used for nuclear activities: *minimal time of exposure, maximum distance from radiation beam, and use of all possible forms of shielding.*[11]

Minimizing doses to patients is usually an effective way to help keep exposures to personnel acceptably low, but it is not sufficient. This is because in general, the patient is exposed only once, while the operator is exposed during all procedures overtime. Professional radiation safety practices of monitoring doses, shielding personnel, managing radiation delivery and maintaining quality improvement programs are also essential.

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