Revista Mexicana de Anestesiología

CONFERENCIAS MAGISTRALES
Vol. 41. Supl. 1 Abril-Junio 2018
pp S135-S138

Radiation exposure risk: backscatter and anesthesia teams

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Radiation exposure is a common fear among anesthesia personnel. Anesthesia personnel potential exposure was due primarily to X-ray examinations performed in the operating room for a variety of reasons, or in the Post Anesthesia Care Unit (Recovery Room) when confirming line placement or examining a patient for complicating events, for example pneumothorax, or pneumoperitoneum. These exposure risks were confined to a single moment when an X-ray examination was performed, with enough opportunity to safely step away and shield oneself from the radiation source while not comprising patient care.

With the development of new technologies, the need for anesthesia has increased in areas utilizing fixed X-ray equipment for interventions. These interventions take many forms, occur in multiple sites, and require elective as well as emergent use of anesthesia expertise and personnel. Examples of these newer fields include Neuro-interventional Radiology, Cardiac Electrophysiology, and Computed-Tomography-Guided Cryoablations. All of these interventions require several hours, with intermittent X-ray examinations or guidance needed frequently, to complete patient care procedures. This leaves the anesthesia care team to care for patients while X-ray studies are performed, potentially exposing anesthesia personnel to x-radiation.

PHYSICS OF RADIATION

Characterization of the risk of exposure, as well as the consequences of repeated, cumulative exposure, to medical radiation is difficult to quantify. In general, radiation is a form of electromagnetic energy with a varying wavelength, from 0.01 to 10 nm (nanometer) wavelengths. The energy associated with these radiation waves ranges from 10 eV (electron volts) to 100 keV. An electron volt is defined as the amount of energy gained (or lost) by a single electron moving across an energy field of one volt, and is the equivalent of 1.6×10^{-19} joules (J). Therefore, a significant amount of radiation exposure must occur to register as energy (eV or keV), if the radiation is at the lower end of energy equivalence; conversely, sources producing radiation with larger energy levels require far less exposure.

The most common forms of radiation exposure the public fears are to gamma rays and X-rays. These rays are substantially different in terms of source and energy level. X-rays are produced from electron energy (for instance, when electrons strike a target or are re-arranged around atoms), with relatively lower levels of energy. Gamma rays are the result of radiation emanating from atom nuclear material (such as during nuclear fission or decay), and generally contain higher levels of energy. It is important to note that X-rays and gamma rays are only the highest two energy forms of radiation: radio waves, microwaves, infrared light, visible light, and ultraviolet light are the other forms of electromagnetic radiation. Only X-rays and gamma rays have enough energy to cause significant tissue damage in a shorter span of time, yet all forms of electromagnetic radiation can cause ionization of tissue and tissue damage given enough time for tissue exposure (e.g. sunburn from visible light/ultraviolet light exposure).

Radiation exposure to tissue is measured and characterized by a separate set of units, which may be more familiar to medical personnel. A system of Grays and Rads is used quantify tissue radiation exposure. The amount of radiation from a source that was needed to cause 1 joule (energy) to be created in 1 kilogram of any tissue was defined as 1 Gray. Gray units were very large amounts of tissue exposure; Rads, defined as 0.1 Gray, i.e. 100 Rad = 1 Gray, were typically used to define tissue exposure due to the relatively more precise description of smaller radiation doses. The system related to human tissue is specifically called the Sievert/Roentgen system, where 1 Gray (Gy) in human tissue = 1 Sievert (Sv). Likewise, 1 Rad (in human tissue) = 1 Roentgen (rem). The conversion factors remain the same: 1 Sv = 100 rem = 1 joule (J) in one kg of **human** tissue.

EXPOSURE TO RADIATION

Radiation exposure is usually thought of as a «ray» coming toward an individual. This is the case with such medical devices as X-ray machines, fluoroscopic examinations, etc. for **patients**. In this type of exposure, the radiation is directed toward a specific area, and this exposure is thus referred to as *direct exposure*. There is also a phenomenon know as *leakage exposure* whereby radiation does not travel toward an intended target area but «leaks» or spreads beyond the area to adjacent structure and personnel. This is thought to occur as the result of using dated or damaged equipment producing the medical radiation for obtaining images. The last type of radiation is *backscatter exposure* whereby radiation aimed at a target reflects and refracts away from the target back toward the source and areas adjacent to the target. This backscatter radiation does not contribute to imaging of structures and is frequently the type of radiation to which medical personnel are exposed. The amount of radiation which scatters is dependent upon the size of the patient and, and as result, the intensity or energy of the radiation needed to obtained an accurate image.

Radiation exposure from a source is dependent upon the distance from the source of radiation. The energy of the radiation decreases as the inverse square of the distance from the source of radiation; that is, exposure is proportional to $1/\chi^2$, where x is the distance (in feet) from the point source of radiation. While this formula is frequently applied to point sources of gamma radiation to determine exposure risk, the same formula is true for x-radiation. Thus, at 4 feet from the source of x-radiation, the exposure (compared to the patient being examined) is 1/64 of the rem delivered to the patient, *if the source is aimed directly at the individual*.

The importance of differentiating direct from backscatter exposure is significant. Most medical exposure is backscattered radiation, yet typically one assumes that the primary exposure is similar to point source radiation directed toward the medical professional.

Protection from exposure thus can encompass distance from the source of radiation as well as attenuation of the radiation by protective equipment. Standard protective equipment worn during X-ray/fluoroscopic examinations includes lead aprons, lead vests, lead skirts, and lead thyroid protectors. It is important to note that this «lead» clothing is actually a combination of heavy metals, including barium, lead, and other metals, in a thickness of 0.3 to 0.5 mm, that help to attenuate radiation exposure. One can also use a leaded glass or Lucite sheet for screening; a 1 inch thick Lucite sheet is the equivalent of or greater than the shielding provided by «lead» protective wear.

MEDICAL CONSEQUENCES OF RADIATION EXPOSURE

Most of the knowledge regarding radiation exposure effects on humans has been obtained from exposure to nuclear fission, either from bomb blast or from power generation plant accidents. There have been longitudinal studies of Japanese survivors of the atomic weapons dropped on Hiroshima and Nagasaki at the close of the Second World War. These studies have looked at the effects of indeterminate, largely extrapolated, exposure to radiation in these survivors. More current studies include the study of individuals exposed to the Chernobyl nuclear reactor accident. There are also longitudinal studies of radiation technologists, which are still continuing. In general, these studies demonstrate that the risk of significant radiation damage increases linearly with time of exposure, rather than a threshold below which no or minimal effects occur.

The first aspect to consider in evaluating the potential for harmful radiation is the dose of ionizing radiation. Different radiographic examinations produce different degrees of radiation to patients. The average yearly dose of «background radiation» from cosmic rays, sunlight, etc. is approximated at 6.2mSv per year. A chest radiograph is 0.3 mSv, a CT scan of the brain is 2 mSv, and a CT of the chest torso is 10-40 mSv, depending on the protocol used for the examination[1]. These exposure numbers for radiographic studies are for patients; the backscatter exposure is not well quantified.

Individual tissues have a varying degree of susceptibility to radiation injury. Thus each exposure to radiation can be «weighted» based on the susceptibility of the tissue to radiation effects. For instance, bone marrow and lungs are far more susceptible to radiation injury than brain tissue. These data are based largely on longitudinal studies of gamma radiation exposure from exposure to nuclear fission, as mentioned above. Longitudinal studies of radiation technologists suffer from inadequate numbers to contribute to weighting of tissue damage from radiation.

One organ that has been of particular interest is the eye, owing to the lack of awareness of radiation effects on the eye. Some interventional radiologists and cardiologists have been wearing protective eyewear for a considerable time, while only recently has the concern been raised that others might benefit from ocular shielding. The assumption in the past has been that the eye receives minimal exposure to radiation and therefore needs minimal shielding. However, some evidence suggests that premature cataract development may occur in some specialties, but the data are not conclusive[(2)]. Furthermore, the estimates for exposure for urologists and interventional radiologists are very low, and these numbers do not approach the maximum recommended allowable exposure dose for the eye[(3-5)].

Anesthesia personnel frequently rotate in and out of procedural suites and therefore have limited or sporadic potential exposure to ionizing radiation. Most often, the «rules of the room» apply such that anesthesia team members are required to wear leaded garments to protect against x-radiation exposure. In one study, it was found that adding an electrophysiology cardiology practice to the coverage of an anesthesia service resulted in an average increase in radiation exposure from 0.5 mSv to 1.0 mSv over a six month time period. Thus the average exposure increased but no detail was gleaned regarding peak exposure risk or individual exposure risk[(6)].

Newer or updated radiographic equipment might be presumed to be more efficient and therefore result in decreased total radiation exposure. One might presume that the digital equipment would be better focused with less «leakage radiation» and therefore some diminished exposure to backscatter. However, the same energy levels must be used to obtain images, and thus backscatter will be similar for a given individual patient and examination. Therefore the patient and the examination required have a greater effect on the production of backscatter radiation than does the equipment used for imaging.

RADIATION EXPOSURE OF ANESTHESIA PERSONNEL

Little specific information has existed regarding the radiation exposure of anesthesia personnel, or indeed ancillary health care staff, when working in areas using radiographic imaging. Examples of such areas include neurointerventional radiology and electrophysiology suites, where anesthesia expertise is needed to accomplish patient care goals. The proximity of the anesthesia personnel to the source of x-radiation frequently causes significant concern among anesthesia providers. We undertook to examine whether the exposure of anesthesia personnel was significant and warranted additional protective equipment, such as ocular shielding with appropriate eyewear, to lessen the radiation exposure.

Our group first examined exposure in neurointerventional cases by using radiologic phantoms to examine whether significant backscatter radiation occurred in a controlled setting. Our results demonstrated that significant exposure occurred in a controlled, simulated case if the anesthesia provider was within 2 feet of the patient at a height of approximately 3 feet; as the distance increased, the exposure amount decreased significantly.

Our second study involved a time and motion study of anesthesia personnel in the electrophysiology suite. In this instance, detectors were placed directly adjacent to the patient (on an IV stand), clipped to the anesthesia provider's hat or mask near eye level, on the anesthesia machine approximately 4 feet away from the head of the patient, and on the anesthesia supply cart approximately 6 feet away from the head of the patient. While a measureable amount of x-radiation was noted from the detector on the IV pole, none of the other detectors registered any radiation exposure in the vicinity surrounding the anesthesia «work area» of the electrophysiology suite. We then examined whether placing detectors at different height very near the patient's head (on an IV pole) would show differences in radiation exposure. We surmised that eyes might be more prone to radiation exposure; however, radiation exposure was far less at the eye levels than 2 feet from the floor. Thus, radiation exposure appears to be highest closer to the patient and to the floor in the electrophysiology suite.

Finally, a recent study has examined the radiation exposure and protection afforded by lead clothing. Hyun et al. measured radiation both outside and inside the lead aprons of proceduralists performing spine surgery. Their findings were that the lead clothing attenuated, but did not block, radiation exposure. This attenuation was between 27% and 47% reduction in exposure at the thyroid and a 38% to 48% reduction in radiation exposure of the torso[(7)]. Thus leaded clothing will offer some protection from radiation exposure, but it should be noted that this clothing merely attenuates but does not prevent radiation exposure.

Our results have indicated that radiation exposure of anesthesia personnel may be far less than has been previously thought, even as the anesthesia work area is, in the case of electrophysiology procedures, very close to the x-radiation source. The fact that lead clothing will attenuate radiation exposure, but not completely block radiation, may be surprising, but comfort can be taken in that the levels of radiation exposure by anesthesia providers is low and may be lowered further by protective lead clothing. The present results of ours and others do not suggest that lead protective wear should be discarded, but rather provide a level of assurance that extreme levels of radiation, such that would cause harmful effects to humans, are extremely unlikely to be experienced in the course of providing anesthesia for procedures. Further work needs to be performed to delineate what the actual exposure levels are and at what heights and distances from patients.

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