Hazards of Ionizing Radiation and its Impact on Spine Surgery

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Key words

- Occupational risk
- Radiation
- Spine surgery

Abbreviations and Acronyms

ALARA: As low as reasonably achievable
CT: Computed tomography
LSS: Life Span Study

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■ BACKGROUND: **Spine surgery relies heavily on imaging, with radiography-based devices being the major operating room imaging modality. Radiation exposure is an occupational risk historically recognized shortly after the discovery of radiation itself. Exposure of both patients and operating room staff is of increasing concern as the knowledge regarding the hazards of radiation is steadily accumulating.**

■ METHODS: **We conducted a literature review of the history of radiation exposure limits and updates on current studies showing the risks of low-dose exposures.**

■ RESULTS: **Multiple studies reporting on radiation exposure risk and methods to reduce exposure risks are discussed.**

■ CONCLUSION: **We discuss the methods to reduce operating room staff exposure to the minimal amount, thus reducing occupational risks. We recognize that increasing awareness to radiation exposure hazards and promoting the knowledge of methods to reduce exposure of surgeons, nurses, and technicians could result in a reduction of exposure to radiation.**

THE HISTORY OF RADIATION EXPOSURE

The history of radiation use in medicine has its origins in the discovery of X-rays in 1895 by Wilhelm Rontgen. It was for this discovery that Rontgen received the first Nobel Prize in Medicine.[1] In an unfortunate turn of events, the US President William McKinley was shot twice in an assassination attempt in 1901. An aide to the president requested Edison to rush an X-ray machine to Buffalo, New York; however, it was never used and the president died 6 days later as a result of septic shock.[2] As for radiation exposure injuries, these could not have arrived early enough, with reports of burns and hair loss in the late nineteenth century. Perhaps the most famous incident of radiation exposure in the beginning of the twentieth century belongs to one of its most prominent investigators: Marie Curie. At the age of 66 years, Curie died of aplastic anemia caused by exposure to tubes of radium in her pockets during research and from mobile X-ray units propelled by her in World War I.[3]

A key player and policy changer in radiation is the International Commission on Radiological Protection, which publishes guidelines for working with radiological materials. The International Commission on Radiological Protection's first publication dates back to 1928, titled *International Recommendations for X-Ray and Radium Protection* (1928).[4]

These recommendations were based on the dose causing acute skin erythema, setting the maximal daily limit at 0.1 Roentgen units, equivalent to 30 Roentgen units given annually. A revised edition, published in 1934, with the same title, states that a person can tolerate 0–2 international Rontgens per day (1 Rontgen is 9.6 mGy units).[5] This study also mentioned that people who work with X-rays and radium should be submitted to general inspections and blood examinations at least twice a year. A further report from 1981 recommends not to exceed 50 mrem above background radiation exposure of individual members of the public.[6]

DEFINITIONS OF RADIATION EXPOSURE

Tissue effects of radiation exposure are seen in virtually all normal tissues. Early reactions from radiation exposure are seen in turnover tissues, in which proliferative impairment results in hypoplasia and late reactions involve parenchymal, vascular, and connective tissue changes, resulting in loss of function.[7] Late effects of radiation exposure are inversely dependent on the biologically equieffective dose, which is modulated by exposure conditions, specifically dose fractionation impact on the responding tissue.[7]

Tissue effects of ionizing radiation are usually divided into 2 categories: the deterministic tissue response and the stochastic response. The deterministic tissue response does not take into consideration radiation carcinogenesis or genetic effects after germ cell exposure. Incidence and severity depend on the dose and there is a threshold dose,[8] with early effects seen in the first weeks after an acute radiation exposure and late radiation effects seen after months to years.[7] The term stochastic effects describes the risk of induction of cancer and heritable disease, with probability increasing with dose; however, no threshold needs to be reached.[8] This has stemmed a term called dosimetry, which aims to assist with optimizing radiation-related procedures through the study of radiation-induced risk.[9]

RADIATION EXPOSURE TO ORGANS AT RISK

Many procedures entail radiation exposure to both patient and treating staff. One of the most common examples is the use of interventional cardiology. Several organs, including the lens, brain, and heart, should be exposed to no more than 0.5 Gy.[7] However, 16%–27% of patients undergoing cardiac catheterization are still exposed to higher radiation levels and the lenses of the treating staff during these interventions have also been shown to be affected by radiation. A study by Vano et al.[10] reported subcapsular lens changes characteristic of ionizing radiation exposure in 50% of interventional cardiologists and 41% of nurses and technicians versus 10% in controls.

If we examine the neurosurgery, the same is true for cerebral embolization, in which 0.5 Gy is the maximal allowed amount of radiation exposure to the brain. In a study in 2014 by Sanchez et al.,[11] 34% of adult patients undergoing cerebral embolization procedures were exposed to radiation doses to the brain higher than the threshold of 0.5 Gy. However, the brain dose is dramatically reduced if the brain is irradiated with narrow nonuniform fields that vary in location, compared with irradiation by large uniform frontal and lateral fields. When using this optimization method, all embolization procedures fall well under the 0.5-Gy radiation exposure.[12] Radiation doses can be minimized by using collimation and limiting fluoroscopy times and dose rates. Yet with all these data, as much as 75% of physicians still underestimate radiation doses from computed tomography (CT), for example.[13]

To try to spare radiation from patients undergoing procedures a concept called ALARA was introduced in 1973. This acronym, which means "as low as reasonably achievable," aims to minimize the amount of radiation exposure to the patient.[14,15] In a recently published study, the senior author suggests that residency programs emphasize radiation exposure education to their residents as well as awareness of reducing radiation energy use, which reduces total exposure of all operating room personal and reduces the risk of serious medical complications.[16]

Some estimates of radiation exposure and cancer are based on the Life Span Study (LSS) cohort of survivors of the atomic bombings in Hiroshima and Nagasaki.[17] The LSS cohort consisted of a large population, including all ages, with a wide range of doses that have been estimated for individual participants, high-quality mortality data, and cancer incidence data. In addition, because the exposure was to the whole body, the LSS cohort offers the opportunity to assess risks for cancers of many specific sites and to evaluate the comparability of site-specific risks. The LSS consists of 93,000 atomic bomb survivors with 27,000 controls.[18]

There are numerous studies estimating cancer rates resulting from radiation exposure. Berrington de Gonzalez et al.[19] estimated that 29,000 future cancers would be related to CT scans performed in adults in 2007 by using risk projection models. In addition, it is estimated that 0.4% of all cancers in the United States are attributable to CT study–induced radiation.[20] This is especially relevant to the pediatric population because their exposure to CT radiation is even more hazardous.[13]

In another study by Brenner et al.,[21] radiation-related cancer mortality risk associated with single or repeated CT examinations was estimated. The investigators concluded an estimated lifetime attributable cancer mortality risk of around 0.08% for a single full-body CT examination and 1.9% for someone receiving 30 full-body CT examinations.

Smith-Bindman et al.,[22] in a retrospective cross-sectional study, estimated radiation exposure during several types of CT examinations in adults. Radiation doses varied from 2 mSv for a routine head scan to 31 mSv for a multiphase abdomen and pelvis CT examination. The investigators state that 1 in 270 adult women undergoing a coronary angiography CT at age 40 years develop cancer as a result of that CT (compared with 1 in 600 adult men). Moreover, 1 in 8100 adult women undergoing routine head CT at the same age (compared with 1 in 11,080 for adult men) develop cancer. The risk is approximately doubled for 20-year-olds.[22]

Fazel et al.[23] reported on the exposure to low-dose ionizing radiation in the general population. Estimating cumulative effective doses of radiation from imaging procedures, they defined annual effective doses as low (<3 mSv), moderate (>3–20 mSv), high (>20–50 mSv), and very high (>50 mSv). With more than 650,000 enrollees undergoing at least 1 imaging procedure associated with radiation exposure, the cumulative effective dose from imaging procedures was 2.4 ± 6.0 mSv per enrollee per year, although there was a wide distribution.[23] The mean effective dose was 0.1 mSv per person per year. This study warrants cumulative effective doses of radiation that exceed 20 mSv per year in approximately 20 million Americans.

Cancer risk is also increased in the pediatric population undergoing imaging because of diseases of the spine.[24] The United Nations Scientific Committee on the Effects of Atomic Radiation, 2013 report states that children exposed to certain radiation doses are at an increased risk of tumor induction compared with adults.[25] In its 54th session, the United Nations committee stated that estimates of lifetime cancer risk for those exposed as children were uncertain and might be 2–3 times as high as estimates for a population exposed at all ages.[26] Pediatric patients with spina bifida have a mean cumulative effective dose of 81.9 mSv and a median cumulative effective dose of 77.2 mSv.[24] Brenner et al.,[27] in an attempt to assess lifetime cancer mortality risks attributed to radiation from pediatric CT, stipulated an increase in dose per milliampere-second and increased lifetime risk per unit dose, thus increasing the likelihood of cancer in the pediatric population.

In a different study by Brenner et al.[27] the question of cancer mortality attributable to radiation from pediatric CT was assessed. Their results showed a sharp increase in cancer rates in the pediatric population, with CT radiation exposure in a 1-year-old being 0.18% for the abdomen and 0.07% for the head, which is 1 order of magnitude higher than for adults.