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REVIEW

Editor’s Choice — Minimizing Radiation Exposure During Endovascular Procedures: Basic Knowledge, Literature Review, and Reporting Standards

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WHAT THIS PAPER ADDS

Objective/Background: This review intends to provide basic knowledge about X-ray physics, biological risks, dose metrics, and radiation protection. It proposes standard nomenclature to measure, estimate, and report dose in order to perform accurate comparisons between publications and practices. A literature review per common procedure type with reference levels is also proposed to allow physicians to evaluate their daily practice.

Context: Endovascular procedures, requiring X-ray guidance, are commonly performed in vascular surgery. X-ray exposure is associated with biological risks for both patients and physicians. Medical X-ray use must follow “as low as reasonably achievable” (ALARA) principles, which aim at using the lowest radiation exposure to achieve a procedure safely. This is underlined by European and international recommendations that also suggest that adequate theoretical and practical training is mandatory during the initial education of physicians. However, the content of this education and professional practices vary widely from one country to another.

Objective: This review aims to summarize the basic knowledge required for vascular surgeons on X-ray physics and image production.

Methods: A panel of endovascular therapists (vascular surgeons and radiologists) and physicists dedicated to X-rays was gathered. International recommendations were summarized. A literature review was performed via MEDLINE to identify studies reporting dosages of common endovascular procedures.

Results: The different mechanisms inducing biological risks, and the associated potential effects on health, are described. Details on dose metrics are provided and a common nomenclature to measure, estimate, and report dose is proposed in order to perform accurate comparisons between publications and practices. Key points of the European and international legislation regarding medical X-ray use are summarized, and radiation protection basics for patients and staff, are detailed. Finally, a literature review is proposed for physicians to evaluate their practice.

Conclusions: Today’s trainees will be highly exposed to radiation throughout their practice. It is thus compulsory that they undergo dedicated radiation education during their initial training, and regular refresher sessions later. In daily practice, focus on dose reduction and monitoring of patient and staff exposure are mandatory.

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INTRODUCTION

According to European legislation,[1] adequate theoretical and practical training must be scheduled during the initial training of physicians and staff exposed to occupational radiation, with refresher sessions thereafter. Furthermore, this basic radiation protection education needs to be expanded for physicians performing procedures that are routinely X-ray guided, such as vascular surgeons, interventional cardiologists, and interventional radiologists,[2] with specific recommendations for the protection of patients from radiation. However, the content and credentials of this training still vary widely from one country to another,

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and so do professional practices. For instance, in France in 2014, the national Nuclear Safety Agency issued a warning to the medical community, as almost 70 exposure accidents had been reported in the last few years, among which seven were regarded as severe accidental occupational exposures. This review intends to summarize the basic knowledge required for vascular surgeons about X-ray physics, biological risks, dose metrics, and radiation protection. It proposes standard nomenclature to measure, estimate, and report dose in order to perform accurate comparisons between publications and practices. A literature review per common procedure type with reference levels is also proposed to allow physicians to evaluate their daily practice.

BASIC KNOWLEDGE

X-ray physics and image formation

X-ray imaging is based on the seemingly simple physics of the interaction of X-rays with matter. X-rays are both electromagnetic waves and particles (photons) that move along straight lines in vacuum. They are powerful enough to penetrate deeply in matter and are able to cross it in certain conditions. In humans, the distribution of the amount and nature of matter is dependent on the anatomy, thus offering different interaction characteristics with X-rays allowing a bi-dimensional projection or shadow image when X-rays are emitted from a point source. The shadow image is obtained as certain parts of the body are more transparent to X-rays than other parts. In all cases, some X-rays are absorbed (entirely or partially) by the body. This absorption effect is called the radiation dose and thus it is inherent to X-ray imaging to create a radiation dose to the patient. Radiation dose is evaluated as the energy released in a reference matter. For entrance dose before the skin, the reference material is the air; therefore:

Air kerma (kinetic energy release in matter) is the dose delivered by the X-ray beam to a volume of air, measured in Gray.

Gray (Gy) One Gy is equal to 1 J/kg. In itself, the energy released in matter is quite small; it takes 4.18 J to raise 1 g of water by 1 °C so that a dose of 1 Gy entirely transferred into a temperature change would raise the temperature of the irradiated water by 0.00024 °C. Unfortunately, the energy released in matter has other effects; the mechanism of creating harm from a radiation dose is described in the section “Biological risks, stochastic and deterministic effects”.

Sievert (Sv) is the unit used to evaluate the impact of biological ionizing radiation on biological tissues. In the specific case of X-rays, and in biological conditions, 1 Gy is equal to 1 Sv.

There are several types of X-ray interactions with matter:

- no interaction—the X-ray simply goes through the matter without interacting with it;
- simple change in direction, called elastic scatter—the X-ray is deviated without a change in energy;
- change in direction and energy, called inelastic scatter or Compton scatter—the X-ray leaves a part of its energy in the matter and emerges from it in a different direction;
- complete absorption, called photoelectric effect—the X-ray energy is completely transferred to the matter.

The scatter effects have two consequences: they create X-rays that do not originate from the same point source, thus blurring the shadow image for scattered X-rays in the direction of the image; for scattered X-rays that are in other directions, this creates X-rays that may reach people located close to the patient, thus creating operator dose.

Equipment that produces X-ray images are essentially composed of an X-ray tube, an image detector with an anti-scatter device on the other side, and a table between them supporting the patient. An X-ray tube emits X-ray photons with a continuum of different energies where the highest energy (in keV) corresponds to the highest voltage applied to the X-ray tube (kVp).

Biological risks, stochastic and deterministic effects

As stated previously, part of the X-ray beam energy is absorbed by the patient. This induces the release of energy in tissues at the origin of biological effects, mediated by two mechanisms.[3] First, there is direct cellular damage, mostly represented by direct DNA breakage, especially in immature, undifferentiated, or dividing cells, such as stem cells. At low dose exposure, DNA repair mechanisms can restore those alterations, but high dose exposure can result in an accumulation of abnormalities, leading to apoptosis and clinical manifestations. Second, indirect cellular damage: ionizing radiation is also responsible for water hydrolysis within the cell. This leads to the formation of hydroxyl molecules (free radical), which combine to form reactive oxidative species such as hydrogen peroxide. Those reactive species tend to bind to proteins to form stable complexes, but this induces loss of essential protein function, and, ultimately, cell apoptosis. Up to two thirds of radiation induced DNA damage could be attributed to this mechanism.[3]

Secondary to these phenomena, two types of biological effects can be seen, with different clinical outcomes. The “deterministic effects” appear once a threshold is overstepped, and their clinical severity is correlated with the intensity of the exposure. Essentially, they represent a risk for patients’ skin and hair, and physicians’ lenses. On the contrary, the onset of “stochastic effects” is not associated with a particular threshold, and so cannot be predicted, but the likelihood of occurrence increases with exposure. They mainly concern repeatedly exposed physicians or staff and, to a lesser extent, patients.

Deterministic effects. The most common manifestation of deterministic effects is cutaneous, and often referred to as radiation induced “skin injury”, or radiation dermatitis.[4] Frequency is estimated to be between 1:10,000 and