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# Radiation Exposure, Dosimetry and Staff Protection in Catheterization Laboratory

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**Abstract**

1.1 Introduction and objective: Effects of radiation became known to physicians in the beginning of the 20th century. Due to the development of cardiovascular imaging and interventions the use of ionizing radiation has increased rapidly in recent years, thus increasing staff and patient exposure, renewing interest in radiation protection.

1.2 State of knowledge: In catheterization laboratory patient exposure to ionizing radiation is unavoidable. Reducing the dose is not only a duty to the patient, but indirectly it applies to the operator as "scattering cloud" exposes the staff to its negative health effects. There are strategies enabling the dose delivered to patients and staff during exposure.

1.3 Summary: Physicians should be aware of the negative health effects of ionizing radiation. In selecting a treatment plan the benefits and risks to the individual should be considered. The reducing of the exposure dose to the patient in the natural way reduces the dose absorbed by the operator during the procedure. Regular quality control in catheterization laboratory, which is the responsibility of their supervisors, combined with radiation protection education also helps reduce exposure to radiation.

**Keywords:** Radiation exposure; Protection; Cardiac catheterization; Occupational hazard

## Introduction

Both positive and negative effects of radiation became known for the first time to physicians experimenting with X-ray generating machines in the beginning of the 20th century [1]. Radiation is undetectable by the senses, therefore a tendency towards the lack of concern regarding potential dangers may lead to serious injury. Due to the development of cardiovascular imaging and increasing number of interventional cardiology procedures the use of ionizing radiation has increased rapidly in recent years, thus increasing staff and patient exposure, renewing interest in radiation protection [2,3]. Interesting reviews and recommendations on patient protection have been written [4-7]. Focused discussion on occupational hazards in catheterization laboratory were initially simultaneous to the rapid increase of the procedures volume, however an increasing number of malignancies and cataracts in interventional cardiologists indicate the need of the risk assessment and ongoing training in the radiation protection [8-10]. Moreover, recent reports suggest even physicians directly applying radiation are unaware of the problem [11].

## Dosimetry

X rays can deeply penetrate the human body, a part of them is absorbed and the remainder passes through the body. This is the basis of X-ray imaging. The decrease amount of the X-ray beam intensity depends on X-ray photon energy as well the density and thickness of the body and the atomic number of atoms constituting the body. The photoelectric process (the X-ray photon absorption and a free electron release) and the Compton scattering (the X-ray photon of lower energy scattering and a recoil electron) are the absorption mechanisms that contribute to the image formation and the tissue damage [12].

In order to assess effects of radiation the following terms are used: absorbed dose, dose equivalent and effective dose. Absorbed dose is the amount of energy absorbed in matter (for instance tissue) per unit mass of irradiated material. The unit of absorbed dose is the gray (1Gy =1J/kg). Absorbed dose includes both scattered radiation and a beam of X-radiation. Dose equivalent means the product of quality factor and the absorbed dose in tissue. The unit of dose equivalent is the sievert (1Sv =1 J/kg). For ionizing radiation it is accepted that 1 Gy=1 Sv. Effective dose is the sum of dose equivalents in the organ or tissue and the weighting factors applicable to each of the body organs or tissues that are irradiated. The unit of effective dose is the Sievert (Sv) as in dose equivalent. Effective dose is used to compare radiation exposure [5,12].

Radiation dose is a measure of human exposure to all types of ionizing radiation. Relatively high radiation doses (10-50 mSV per procedure depending on imaging modality) are used in vascular imaging and exposing mainly patients to its harmful effects although staff is exposed to smaller doses of radiation almost on a daily basis. For this reason occupational radiation exposure is the sum of all doses from all sources of ionizing radiation for each person [12]. An individual dose for operator varies from 0.04 to 38 μSv per procedure [4]. According to Kim et al. who reviewed the literature from the early 1970's to the present, the effective doses ranged from 0.02-38.0 μSv for diagnostic catheterizations, 0.17-31.2 μSv for percutaneous coronary interventions, 0.24-9.6 μSv for ablations and 0.29-17.4 μSv for pacemaker or intracardiac defibrillator implantations [13-19]. The radiation staff dose limits may differ from country to country. For example, in Poland they are set at:

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- An effective dose of 20 mSv per year averaged over 5 consecutive years,
- An effective dose of 50 mSv in any single year,
- An effective dose of 100 mSv over 5 consecutive years provided that the effective dose of 50 mSv is not exceeded in any single year,
- An equivalent dose to the lens of the eye of 150 mSv in a year,
- An equivalent dose to the extremities (hands and feet) of 500 mSv in a year,
- An equivalent dose to the skin of 500 mSv in a year, which applies to the average dose over 1 cm2 of the most highly irradiated area of the skin [20].

Dose Area Product (DAP) is a quantity used in objective assessment of the ionizing radiation beam. It reflects the dose within the radiation field and the area of tissue irradiated and is expressed in $Gym^2$. The DAP is independent of the distance between the X-ray tube and the measuring device because the further away from the X-ray tube this measurement is taken, the more the area of exposure increases. There is an inverse square relationship regarding the the dose and the area exposed, thus, as you get further away the area of exposure increases, so in total, DAP remains constant regardless of distance from source. Most radiographic machines are equipped with DAP meters or computer programs that calculate the DAP from initial exposure parameters. They also calculate Interventional Reference Points (IRP) which approximately indicates the level of patient's skin to characterize patient exposure. The sum of kinetic energy of particles that have been charged in air is defined as kerma (kinetic energy released per mass) and is expressed in Gy. Kerma at the IRP is measured and displayed in real time during the procedure. Depending on the beam characteristics, the C-arm angulation and the patient's size, IRP location may not necessarily reflect the real skin level. Therefore, this measurement should be use for guidance only and should not be considered as a real skin dose [12,14-19].

## Effects of Radiation on the Human Body

In order to assess the effects of radiation to the human body it does not suffice to calculate the absorbed dose, but it is important to identify other factors such as type of radiation, irradiated body area, organ or tissue, dose distribution over time, type of irradiation (internal or external), gender, age and health status, species and individual sensitivity [2,16,18]. The harmful effects of radiation on the human body are divided into stochastic and deterministic [12,21].

The main stochastic effects are carcinogenesis and genetic mutation. DNA damage leads to a loss of cell function due to DNA single- or double-strand breaks, DNA strand and protein cross links, pyrimidine- and purine-derived base damage. A dose of about 1-2 Gy causes DNA single-strand breaks >1000/cell, base damage >1000/cell and DNA double-strand breaks over 40/cell [22]. DNA double-strand breaks are most difficult to repair and may lead to cell death. DNA double-strand breaks are caused directly by ionizing radiation or indirectly by free radicals formed from water molecules. The main negative effect is mutation or carcinogenesis. In most cases intracellular repair mechanisms are able to remove the lesions. Cell division before DNA repair can lead to replication of the mutation [23]. These all result in neoplasm induction or heritable abnormalities. The probability of stochastic effect in an individual increases with the increasing effective dose, however no threshold can be identified. Furthermore, a delay from irradiation to effect may reach decades and direct relationship is not easily detectable. In a very large dose registry of radiation workers a significant increase in the risk of cancer with an increasing dose has been observed [24].

Deterministic effects are well defined and their appearance and severity is single dose-related. Radiation-induced skin injury is the most common and it occurs after the exposure over a relatively small body area. It can be classified as type I (erythema and exsudative dermatitis in a week after the procedure), type II (vascular endothelitis with ulcerations at four to 8 months after exposure) and type III (necrosis after a few weeks after exposure) [24]. Radiation-induced lens opacity and cataract are also typical complication of prolonged X-ray application (threshold dose exceeds 1-2Gy). Although operator's head is not usually located in the primary beam, due to repeated procedures and the dose needed to develop these injuries, staff are likely at greater risk [12].

## Principles of Radiation Protection

The use of ionizing radiation in medicine causes radiation exposure to both staff and patients. Each staff member should be familiar with the principles of radiation protection, understand the role of shielding, distance from a source of radiation and time of exposure. One goal of radiation safety is to keep radiation exposure ALARA (As Low As Reasonably Achievable) [2,6].

Distance from a source of radiation, time of exposure and shielding are the key components of radiation protection:- distance from a source of radiation should be the greatest possible; it is the simplest principle of radiation protection that applies to staff members

- the time of fluoroscopy and cinematography should be the shortest possible

-appropriate shields (type and thickness depend on the energy and the intensity of ionizing radiation) should be used; inappropriate shielding may increase staff exposure and may not limit the doses absorbed, all staff members exposed to radiation should wear aprons, physicians and scrub nurses should wear aprons protecting the front of the body, whereas operating room nurses should also protect the back; it is recommended to wear collars protecting the thyroid and glasses, especially by operators who are exposed to radiation more than other staff members.

Radiation shields can be movable (stands, door), personal (gloves, aprons) and structural (door, walls and floors). Staff is also exposed to scattered radiation which arises from interactions of the primary radiation beam with the patient's body. Greater the patient protection, the better staff protection through reduction of scattered radiation. A ceiling-suspended radiation shield has been reported to be the most efficient eye dose-reducing protection strategy for operators [25].

Individual exposure to scattered radiation is measured with personal dosimeters: film badges, thermo luminescence badges and pocket ionizing chambers. Workers exposed to ionizing radiation are divided into categories according to Atomic Energy Law. Category A workers are those who are liable to receive an effective dose >6 mSv/year. Such workers need to be monitored for exposure and should wear two dosimeters: one at a position facing the radiation source for instance on the collar to face the thyroid or on the shoulder, the other one under a protective apron. Category B workers are those exposed to an effective dose of 2-6 mSv per year, they may be monitored at workplaces and they may wear personal dosimeters. Data regarding radiation exposure over consecutive years are stored in accredited reference centers where personal dosimeters are checked. When analyzing the effect of work

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environment on health status it is the only documentation regarding occupational exposure that can be referred to.

It is extremely important to utilize machines capable of generating ionizing radiation that are equipped and designed to reduce radiation exposure. Such devices should be constructed in the way that enables collimation of the useful X-ray beam, provides shields for leakage radiation and enables adequate filtration. The number of patients undergoing repeat interventional procedures that use ionizing radiation increases from year to year, the radiation dose delivered to the patient may be a thousand times greater than the dose received by staff. As the radiation is delivered directly to the skin the dose received by patients is measured in Grays (Gy), and not in Millisieverts (mSv) [2]. Available devices (for instance angiographic machines) are required to provide real-time measurements of the absorbed skin dose in patients. If the delivered skin dose exceeds 1 Gy, this instance should be recorded in medical documentation of the patient, and when the dose exceeds 3 Gy, the patient should be monitored for 14-28 days and referred for laboratory test (blood smear and morphology). Data regarding doses received by patients during procedures that use ionizing radiation should be stored in radiological centers. Lists of patients in whom the dose exceeded 1 Gy and 3 Gy should also be available [26].

The following principles are regarded useful in catheterization laboratory [4,27,28]:

- Patients should be exposed to radiation only when necessary. Initial patient positioning, advancement of catheters into the aortic root through the sheaths should be done under minimum fluoroscopic control.
- Reducing the number of acquisitions to the minimum necessary.
- Acquisition time should not exceed 3 s.
- Regular work at lower doses of ionizing radiation.
- The patient should be placed in the optimal position for C-arm access i.e. as close to the image amplifier and as far from the tube as possible.
- The smallest C-arm angulation in case of extended fluoroscopic exposure. Adjustment of C-arm angulation during prolonged procedures.
- Using collimators to reduce the irradiated area.
- Using the lowest magnification, accepting the best quality image.
- Using a pulsed fluoroscopy at lowest framing rates.

Regardless of general agreement that ionizing radiation is considered harmful, the "radiation hormesis" theory have been established to further explore biological effects of low-dose ionizing radiation. This theory, although controversial, is based on the principle that low doses of radiation (but higher than natural level) stimulates cellular repair mechanisms and thus protects from the disease. Those mechanism remain incompletely understood and more cellular and clinical research in is necessary to determine whether the encouraging hormesis theory is true or false. Whatever the conclusion will be, currently major radiation protection bodies agree that radiation should be considered harmful at any dose and that the protection rule of minimizing the patient's exposure to protect the operator remains valid [4,29].

## Summary

Rapid progresses in computer technology and easy access to procedures with ionizing radiation have resulted in the development of novel invasive and noninvasive diagnostic procedures with major medical benefit. However, one should be aware of the negative health effects of ionizing radiation and enable the dose reduction delivered to patients and staff. In selecting a treatment plan the benefits and risks to the individual should be considered. In catheterization laboratory patient exposure to ionizing radiation is unavoidable. Although no dose may be considered safe, sometimes it may be warranted to achieve more than average doses during primary PCI. Reducing the dose is not only a duty to the patient, but indirectly it applies to the operator as some of the radiation leaving the human body is scattered exposing the staff to its negative health effects. The reducing of the exposure dose to the patient in the natural way reduces the dose absorbed by the operator during the procedure. Regular quality control in catheterization laboratory, which is the responsibility of their supervisors, combined with radiation protection education also helps reduce exposure to radiation [30].

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