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Original paper

The influence of operator position, height and body orientation on eye lens dose in interventional radiology and cardiology: Monte Carlo simulations versus realistic clinical measurements

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ABSTRACT

Objective: This paper aims to provide some practical recommendations to reduce eye lens dose for workers exposed to X-rays in interventional cardiology and radiology and also to propose an eye lens correction factor when lead glasses are used.

Methods: Monte Carlo simulations are used to study the variation of eye lens exposure with operator position, height and body orientation with respect to the patient and the X-ray tube. The paper also looks into the efficiency of wraparound lead glasses using simulations. Computation results are compared with experimental measurements performed in Spanish hospitals using eye lens dosemeters as well as with data from available literature.

Results: Simulations showed that left eye exposure is generally higher than the right eye, when the operator stands on the right side of the patient. Operator height can induce a strong dose decrease by up to a factor of 2 for the left eye for 10-cm-taller operators. Body rotation of the operator away from the tube by 45°–60° reduces eye exposure by a factor of 2. The calculation-based correction factor of 0.3 for wraparound type lead glasses was found to agree reasonably well with experimental data.

Conclusions: Simple precautions, such as the positioning of the image screen away from the X-ray source, lead to a significant reduction of the eye lens dose. Measurements and simulations performed in this work also show that a general eye lens correction factor of 0.5 can be used when lead glasses are worn regardless of operator position, height and body orientation.

1. Introduction

The International Commission on Radiological Protection has recommended a reduction of the occupational dose limit for the eye lens from 150 mSv to 20 mSv, averaged over 5 years, with no single year exceeding 50 mSv [1]. This change has been incorporated into the European and International Basic Safety Standards [2,3]. Furthermore, several studies performed on operators in interventional cardiology and radiology (IC/IR) have shown that this newly recommended limit of 20 mSv can be exceeded in numerous cases [4–9].

International organizations, such as the International Organization for Standardization and the International Electrotechnical Commission [10,11], have stressed the importance of radiation protection tools for eye lens dose reduction in IC/IR. The ceiling suspended screen, when correctly positioned, and the lead glasses, are two of the most important tools that can provide this protection. Even though the lead screen provides high protection, often its usage is not practical and it can impede the operator's work. In these cases, lead glasses are an alternative solution. Several studies performed using Monte Carlo simulations or phantom studies in clinical environment have investigated the efficiency of lead glasses [12–17]. However, such data correspond to static situations whereas, in clinical routine, operators move along the patient. To this day, very few measurements have been performed during clinical practice on operators. In general, these measurements highlight that the attenuation of the ceiling shielding and lead glasses is lower than the nominal value provided by manufacturer. In fact, primary beam attenuation largely overestimates the glasses protection efficiency. Other factors, such as the radiation impinging on the eyes laterally or from beneath the glasses,

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through the gap between the face and the glasses themselves, and the contribution from radiation scattered by the unprotected part of the operator's head, are of concern [12].

The present work, organized within the EURADOS working group 12 (Dosimetry in Medical Imaging), aims, on the one hand, at studying the influence on the eye lens exposure of operator position, height and body orientation using Monte Carlo simulations and, on the other hand, at studying the protection efficiency oflead glasses in real clinical conditions. More specifically the following parameters were studied:

– the effect of operator position with respect to the patient when lead glasses are not worn;
– the influence of the presence of the image intensifier, the tube voltage and the operator's height;
– the protection efficiency of lead glasses for different operator positions and body orientations with respect to the patient;
– a comparison of the estimation of lead glasses protection obtained with static Monte Carlo situations against measurements performed in real clinical conditions.

2. Materials and methods

2.1. Monte Carlo simulations

The MCNPX v.2.5 Monte Carlo code was used [18] to study the influence of different parameters on operators' eye lens dose. The simplified IC/IR scenario defined in the framework of the European projects ORAMED [19] and ELDO [14] was adopted in this study. In these simulations, both the patient and the operator, who stands on the right side of the patient, were represented by two modified anthropomorphic ORNL-MIRD phantoms [20]. Very thin tally volumes of 4 10^{-3} mm thickness were introduced at a depth of 3 mm in the soft tissue of the eye to calculate the personal dose equivalent $H_p(3)$. $H_p(3)$ was calculated by using the energy deposition tally (F6 tally) in kerma approximation mode, disregarding the transport of secondary generated particles for the left and the right eye. A 90 kV peak-voltage X-ray beam with 3 mm Al added filtration was used. The reference operator height is 178 cm.

A first study was carried out in order to evaluate the influence of operator position and body rotation on eye lens dose when lead glasses are not worn. Several distances (0, 20, 40 and 70 cm) between the operator and the X-ray source were considered together with the following operator body orientations: 0°, 10°, 30°, 45° and 60°, towards and away from the tube. A simplified sketch of the configurations is illustrated in Fig. 1. The selected distances represent the position of the operator for jugular access (0 cm), radial access for pediatric (20 cm) and adult patients (40 cm) and femoral access (70 cm). For these simulations (Fig. 2b), a postero-anterior projection is considered. The patient is lying down on the table in the supine position, with the X-ray field centered on the patient's thorax and the radiation going from the back to the front.

Depending on the relative position of the operator, the image intensifier can provide attenuation of the scattered radiation that reaches the operator eye. In order to investigate this, a cylindrical lead shell of 2-mm-thick filled with air and an input window of 1.5 mm aluminum were used to represent the image intensifier. Simulations were repeated by replacing the lead and aluminum materials by air, for the above mentioned distances. The rotation of the operator with respect to the source was not considered.

The effect of tube voltage on the operator eye lens was studied by repeating calculations for a 110 kV peak voltage radiation beam with 3 mm aluminum added filtration at distances of 0, 20, 40, 70 cm and 0° rotation. Eye lens dose values were compared against the beam with lower voltage (90 kV). The higher voltage is usually set for a larger patient.

In order to study the influence of eye lens exposure for an operator who is either shorter or taller than the reference operator, calculations for operator heights of 158, 168 and 188 cm were also included. Simulations were performed for distances of 0, 20, 40, 70 cm and 0° rotation.

In order to study the efficiency of the lead glasses the wraparound style was modeled as defined in Koukorava et al. [14] with 0.5 mm lead thickness and 7.5 mm lens size (Fig. 2a). Two field dimensions were investigated in this scenario resulting in a 30 and 20 cm diameter field at the level of the patient thorax, for postero-anterior and left-lateral projections respectively (Fig. 2b). When using lead glasses, ISO 15382 [10] recommends to use a

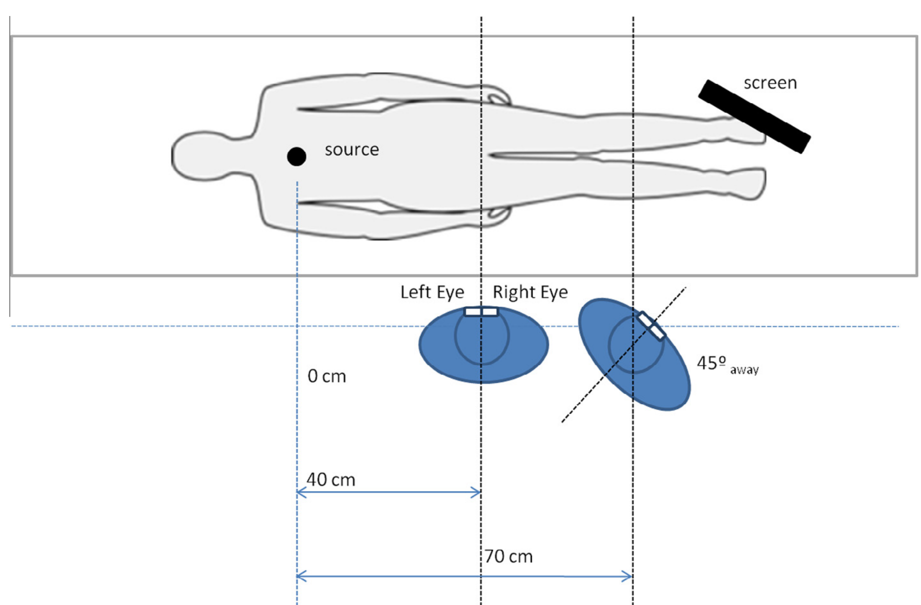

Fig. 1. Simplified geometry with some of the possible configurations of the clinical simulated scenario. In this figure the operator is at 40 cm distance and 0° orientation (no rotation) and at 70 cm distance and rotated 45° away from the source (towards the image screen).

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