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Scatter radiation dose at the height of the operator's eye in interventional cardiology

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HIGHLIGHTS

- Different C-arm angulations can modify the scatter dose rate.
- Scatter dose rate increase linearly with patient entrance dose rate.
- Operator could exceed threshold for lens opacities if protection tools are not used.
- There is a good linear correlation between kerma-area product and scatter dose.

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ABSTRACT

This paper presents the first experimental result for scatter dose at the height of the operator's eye measured for a Polymethyl methacrylate (PMMA) phantom simulating an adult patient in an interventional laboratory at Belo Horizonte, Brazil. Values for scattered radiation doses at the height of the operator's eye are reported for procedures performed with and without a ceiling-suspended screen. Correlations between scatter radiation doses and different angiographic projections, phantom entrance dose and kerma area product, were obtained.

Experimental measurements were made in an angiography X-ray system equipped with flat-panel detector. A cine and three fluoroscopy modes: low, medium and high dose were available. Scattered radiation doses were measured at three angiographic projections: anterior-posterior (AP), left anterior oblique 90° and left anterior oblique 45° with cranial 30° (spider) angulations. The detector measuring scatter radiation was positioned at the usual distance of the cardiologist's eye and the detector measuring phantom entrance dose was positioned at the bottom of the PMMA phantom.

The phantom entrance dose for fluoroscopy low, medium, high and cine were 15, 29, 36 ± 4 and 184 ± 18 mGy/min, respectively to AP projection. A good linear correlation exists between phantom entrance doses rate and scatter dose rate to AP projection. There is a good linear correlation between the kerma-area product and scatter dose at the height of the operator's eye, coefficient of determination R^2 were 0.9728 and 0.9913 with and without ceiling-suspended screen. An experimental correlation factor of 0.1 and 3.5 μSv/Gy*cm2 has been found for the AP projection with and without ceiling-suspended screen, respectively. Scatter dose at the eyes cardiologist position depends on the C-arm angulation an increase of the scatter radiation dose by a factor of 5 was found.

The highest dose rate in the lens was 19.74 ± 1.97 mSv/h without ceiling-suspended screen in cine mode for "spider" projection. For lateral projection in cine mode, the ceiling-suspended screen reduced dose by a factor 0.01. Interventional operator may therefore easily exceed the lens dose limit if ceiling-suspended screen is not used.

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1. Introduction

Recent studies among radiology technologists (Chodick et al., 2008), astronauts (Cucinotta et al., 2001), survivors of the atomic bomb (Nakashima et al., 2006; Neriishi et al., 2007) and those who were exposed to the Chernobyl disaster (Worgul et al., 2007) suggest the possibility of a significant risk of lens opacities at doses lower than 1 Gy. This may happen after several years of exposure, similar to that which may be found in occupational practice.

In 2011, in view of evidence showing eye lens injuries due to radiation, the International Commission on Radiological Protection (ICRP) issued a statement that threshold doses are or may be lower than previously considered. For the lens of the eye, the absorbed dose threshold is now considered to be 0.5 Gy. For occupational exposure, an annual equivalent dose limit in lens of the eye of 20 mSv, averaged over defined five-year periods and with no single year exceeding 50 mSv (ICRP, 2011).

Studies have reported cases of radiation-induced cataract among cardiology professionals (ICRP 85, 2000). Vano et al. (1998) estimate a range from 450 to 900 mSv per year for the lens injuries, sustained over several years without the use of ceiling-suspended screens. Recent surveys regarding the high prevalence of lens changes likely induced by radiation exposure suggest an urgent need for better training in radiation safety, in addition to the use of eye protection during interventional procedures and optimization of staff protection apart from improving occupational dosimetry (Vano et al., 2011a, 2013b; Donadille et al., 2011; Rehani et al., 2011).

The crucial issue is preventing cataracts in staff members in intervention rooms. In 2000, the ICRP recommended using a dosimeter over the lead apron in interventional radiology to estimate eye lens dose (ICRP, 2007). Combining several shielding types (table-suspended drapes, ceiling-suspended screen, protective aprons, leaded eyeglasses, mobile shields and disposable drapes) results in a dramatic dose reduction for the operator. This should be the norm, rather than the exception (Duran et al., 2013). As reported in the ORAMED (Optimization of RAdiation protection for MEDical staff) project, only 36% of cardiology operators wear lead glasses, with only 25% of operators in other interventional procedures doing so (Vanhavere et al., 2011). Moreover, in 31% of cases no collective protective equipment was used and in only 44% of cases were table shielding and ceiling screen used (Donadille et al., 2011).

Occupational dosimetry remains a challenge in fluoroscopy-guided procedures. Numerous variables must be taken into account in estimating eye lens dose. One approach includes assessing existing occupational dose to estimate the scatter dose to the eye lens (Vano et al., 1998, 2006; Donadille et al., 2011; Vanhavere et al., 2011). Research conducted by Vano et al. (2011b) in ten interventional cardiology centers in Latin American countries reported that only 64% of occupationally exposed individuals wear the individual monitor (dosimeter) and only 36% admitted knowing the meaning of their dosimetry. Other research performed by the International Atomic Energy Agency (IAEA), with cardiologists from over 56 countries participating, found that only 33–77% of interventional cardiologists wear their dosimeters regularly (IAEA, 2004).

Another approach uses values from experimental measurements taken at certain positions, typical for cardiologists, at representative catheterization laboratories, reproducing protocol cardiology procedures with different fluoroscopy and cine acquisition modes (Vano et al., 2008, 2013a). Using the Monte Carlo simulation represents a further approach to estimating scatter dose level in interventional procedures. Numerical simulations can play an important role when evaluating extremity and eye lens doses in correlation with many different parameters. However, the dynamic of procedures is so complex (collimation change, X-ray beam filtration, angles, kV, mA, pulse, filters, operator position, etc.) that it remains difficult to take all factors into account (Carinou et al., 2011; Koukorava et al., 2011).

One method to optimize radiation exposure is measuring the entrance surface air kerma (ESAK) and kerma-area product (KAP) for patient and scattered dose rate at staff position under clinical working conditions, using phantoms and defined technical factors. Correlating ESAK and KAP with the scatter dose, applying the relevant attenuation factors for protective devices can enable estimation of lens doses for operators (Ubeda et al., 2010; Vano et al., 2009).

This paper presents the first experimental results for scatter dose at the height of the operator's eye measured for a PMMA phantom simulating an adult patient in an interventional laboratory at Belo Horizonte, Brazil. Values for scattered radiation doses at the height of the operator's eye are reported for procedures performed with and without a ceiling-suspended screen. Correlations between scatter radiation doses and different angiographic projections, ESAK and KAP, were obtained.

2. Materials and methods

Experimental measurements were taken in a cardiac laboratory using a Philips Allura Xper FD10 angiography X-ray system (Philips Medical Systems Nederland B.V) equipped with an amorphous silicon flat-panel detector. A diagonal dimension of 25 cm was used for field of view. Three fluoroscopy modes were available: low (FL), medium (FM) and high (FH) dose, all configured at 15 pulse s^{-1}, whereas a cine mode (CI) was typically used at 15 frame s^{-1}. Measurements were obtained in a static geometry for three angiographic projections, nomenclature for radiographic projection used in interventional cardiology were: anterior-posterior (AP) (X-ray tube undercouch, see Fig. 1), left anterior oblique 90° (LAO90) (X-ray tube in the lateral C-arm) and left anterior oblique 45° with cranial 30° angulations (LAO45CRA30° or spider) and a "cardiac" protocol the most common for patient between 70 and 90 kg.

Fig. 1. Experiment arrangement, AP projection with use of a PMMA phantom of 20 cm, for measurement of phantom entrance dose (ESAK) (a) and scatter dose (b). Ceiling-suspended screen (c) and Flat panel detector (FD) (overcouch).