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Eye lens dose correlations with personal dose equivalent and patient exposure in paediatric interventional cardiology performed with a fluoroscopic biplane system

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ABSTRACT

Purpose: To analyse the correlations between the eye lens dose estimates performed with dosimeters placed next to the eyes of paediatric interventional cardiologists working with a biplane system, the personal dose equivalent measured on the thorax and the patient dose.
Methods: The eye lens dose was estimated in terms of $H_p(0.07)$ on a monthly basis, placing optically stimulated luminescence dosimeters (OSLDs) on goggles. The $H_p(0.07)$ personal dose equivalent was measured over aprons with whole-body OSLDs. Data on patient dose as recorded by the kerma-area product (P_{KA}) were collected using an automatic dose management system. The 2 paediatric cardiologists working in the facility were involved in the study, and 222 interventions in a 1-year period were evaluated. The ceiling-suspended screen was often disregarded during interventions.
Results: The annual eye lens doses estimated on goggles were 4.13 ± 0.93 and 4.98 ± 1.28 mSv. Over the aprons, the doses obtained were 10.83 ± 0.99 and 11.97 ± 1.44 mSv. The correlation between the goggles and the apron dose was $R^2 = 0.89$, with a ratio of 0.38. The correlation with the patient dose was $R^2 = 0.40$, with a ratio of 1.79 μSv Gy^{-1} cm^{-2}. The dose per procedure obtained over the aprons was 102 ± 16 μSv, and on goggles 40 ± 9 μSv. The eye lens dose normalized to P_{KA} was 2.21 ± 0.58 μSv Gy^{-1} cm^{-2}.
Conclusions: Measurements of personal dose equivalent over the paediatric cardiologist's apron are useful to estimate eye lens dose levels if no radiation protection devices are typically used.

1. Introduction

Interventional cardiology (IC) is a medical speciality with high exposure to ionising radiation, both for patients and staff [1]. Although these procedures are minimally invasive and offer advantages over surgery for certain diseases, the development of new practices has led to an increased number and complexity of procedures in recent years, subjecting patients and operators to higher radiation doses than those encountered in general radiology [2]. There is increased interest in occupational doses to the professionals involved in these procedures since the April 2011 International Commission on Radiological Protection (ICRP) statement [3], which is covered by the new 2013/59 Euratom directive of December 5, 2013 [4]. This new European directive reduces the equivalent dose limit for the eye lens in planned occupational exposure situations from 150 to 20 mSv per year, averaged over 5-year periods, such that doses of 50 mSv in a single year are not exceeded. This limit can be exceeded if radiation protection measures are not used in procedures performed on adult patients [5–7]. In paediatric IC, lower doses to child patients than to adult patients have recently been reported [8–10]; thus, lower doses in the exposed practitioners' eye lenses are expected, although longer interventions are typically observed and protective ceiling-suspended screens are often not used [12]. Although literature detailing the operational implications of applying this limit in paediatric patients is scarce, interest is growing [11,13,14].

Various dosimetric methods for estimating the dose to the lens are available, from personal dosimeters placed over the lead apron [15] to thermoluminescent dosimeters located at eye level [16]. Recent efforts have been made to evaluate various approaches to properly estimating the eye lens dose during interventional procedures, analysing the influence of both the type and position of the dosimeter [17]. Likewise, the use of optically stimulated luminescence dosimeters (OSLDs) to monitor eye lens doses in the interventional environment is currently under analysis [13,18,19].

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OSLDs have the advantage of high sensitivity, rapid readings and the ability to read the absorbed dose multiple times [20,21], features very useful for a medical physics department. Moreover, their high dependence on energy in the radiology range can be corrected [21] and its uncertainty taken into account [13,19]. In terms of paediatric IC eye lens dose measurements, some of these features (such as high sensitivity) might be particularly useful because paediatric patients present high morphological variability, with generally smaller thicknesses than adults, and these procedures are performed using equipment adjusted to low-dose rates [22,23].

To monitor the eye lens dose, the recommended operational quantity is $H_p(3)$ [24,25], although there are currently no available conversion coefficients in international standards, and dosimeters designed for $H_p(3)$ are not widely available [26]. A number of authors have recently attempted to provide air kerma-to-$H_p(3)$ conversion coefficients for RQR radiation qualities, typical for IC [27]. However, other authors have suggested that $H_p(0.07)$ is sufficiently reliable for the photon energy involved in radiology and IC [18,26,28–30].

To assess the dose levels to the lens of the eye in paediatric IC prior to routine monitoring [30], a correlation study was performed comparing the eye lens dose estimations performed in terms of $H_p(0.07)$ with nanoDot OSLDs placed next to the eyes of the only two paediatric interventional cardiologists working with a biplane system in the facility and the $H_p(0.07)$ personal dose equivalent measured with whole body InLight OSLDs on the thorax, over the left side of their lead aprons. Moreover, the relationship between the dose to the cardiologists' lenses and the patient dose, in terms of kerma-area product (P_{KA}) [31], was also analysed. The measurements were performed during interventions, on a monthly basis, from March 2014 to February 2015. Because the paediatric patients are usually small-sized and the procedures are complex, the use of a ceiling-suspended screen is often uncomfortable for correct work and is frequently disregarded. On the other hand, the nanoDots were placed on the external side of the cardiologists' lead goggles to hold them tightly in the vicinity of the left eye. Therefore, in this survey, no radiation protection devices were usually considered.

2. Materials and methods

2.1. Dosimeters, detectors and X-ray equipment

The dosimetry equipment used in this study consisted of a set of photo-luminescent crystal dosimeters called screened nanoDots (Landauer Inc[1], IL, USA), an OSL reader (MicroStar, Landauer Inc.), an automatic annealer (InLight Annealer, Landauer Inc.) and an external PC with custom software. The nanoDots are composed of an active material (Al_2O_3:C) measuring 4 mm in diameter and 0.3 mm thick, and they are covered with a $10 \times 10 \times 2$ mm^3 light-proof (when closed) plastic casing. InLight whole body OSLDs were also used in this study to obtain the personal dose equivalent over the aprons. InLight dosimeters are built with an $83 \times 35 \times 15$ mm^3 case, with metal and plastic filters, and a 4-position Al_2O_3:C detector slide component.

Prior to the eye lens dose measurements, the nanoDot dosimetry system was validated with irradiations performed using a general radiography unit (Digital Diagnost, Philips Healthcare) and a flat ionisation chamber (model 10x5-60) with a Radcal 9015 radiation meter (Radcal[2], CA, USA). The ionisation chamber was calibrated by official calibration laboratories, and had an energy dependence lower than 5% for the energy range employed. The in-room IC equipment was a Siemens Artis Zee VC14 biplane angiographic X-ray system, equipped with two 100-kW generators at 125 kV and 2 flat amorphous silicon detectors with caesium-iodide scintillators. The tube was a Megalix CAT Plus model (Siemens), tri-focus (0.3, 0.6 and 1 mm), with a 12.5° tungsten-rhenium anode and a 2.5 mm Al inherent filtration. This equipment typically uses the Cardio 3040 Siemens protocol, with 3 fluoroscopic modes (high-dose fluoroscopy FL3040$^+$, normal fluoroscopy FL3040 and low-dose fluoroscopy Fl3040$^-$), and acquisition or cine (LV3040). A rotational 3-D acquisition or cone-beam computed tomography (CBCT) is also used (with a cardiac diagnostic protocol 5sDRc and a low-dose protocol 5sDR-L). The default fluoroscopy mode is 10 pulses per second (ps^{-1}), although the two cardiologists (who are trained and certified in radiological protection according to national regulations) routinely use 3 ps^{-1} to reduce the patient dose when image quality is not a concern. In cine mode, the default configuration is 30 frames per second (fs^{-1}), which is routinely used. The CBCT acquisition is performed with 26.6 fs^{-1} and a 5-s acquisition time. The characteristics of the evaluated X-ray beams were measured using a beam analyser detector calibrated for the energy under consideration (Unfors RaySafe Xi Base Unit and R/F detector[3]). The beam analyser has an uncertainty in half-value layer (HVL) measurements of less than 10% for the energy range employed. To collect all the workload data, including the P_{KA} values of both planes to study the correlation between patient and staff eye lens dose, the automatic dose management software CareAnalytics (Siemens) was used.

2.2. Dosimetry system validation, reading process and calibration

Prior to the measurement process, various tests were performed to validate the OSL dosimetric system: reproducibility, linear dose-response, signal depletion from readouts and lower detection limit. The first 3 tests were performed according to Al-Senan's procedure [21]. The lower detection limit (LD) was obtained according to Sonder et al. [32]. Dosimeter reproducibility was found to be between 0.8% and 1.3%, and good linearity between the nanoDot response and the ionisation chamber dose was obtained, with R^2 higher than 0.99 ($p < 0.05$). The correction factor d for decrease of signal per readout was found to be 0.995 ± 0.002. The lower detection limit in terms of $H_p(0.07)$ was found to be 16 μSv. Lastly, and as part of the MicroStar reader's quality control (QC) procedure,[4] the reader's stability was tested every day before measurements, analysing the response of the photomultiplier tube after undergoing a stimulus from a set of light-emitting diodes, and with no stimulus present. The reader was considered stable if no response exceeded the corresponding mean and variance control limits [33,34].

The reading process consists of 5 successive readings, correcting each reading by the corresponding signal depletion f_d. The average of the last 4 readings was considered the best estimate of the cumulative counts in the dosimeter, and uncertainties in type A (due to the dispersion of the readings) and type B (due to the resolution and stability of the reader) were taken into account [35]. The best estimate of the counts obtained during a single irradiation, C, was considered to be the average counts after the exposure minus the average residual counts remaining after the annealing.

The system was calibrated in terms of *kerma* and $H_p(0.07)$, using 15 pre-irradiated nanoDots provided by the manufacturer, exposed to 5 air-kerma levels: 0 (unexposed), 3.37, 20.27, 337.83 and 675.67 mGy (uncertainty in the irradiation of 5%, coverage factor k = 2). The beam quality used was RQR6 [36] (80 kVp, average energy 44 keV and HVL of 3.01 mm Al). The microStar reader

[1] http://www.landauer.com.
[2] http://www.radcal.com.
[3] http://www.raysafe.com.
[4] N. T. Ranger (2012) microStar Reader Quality Assurance Programme. http://solutions.landauer.com/images/site/microstar/documents/microstar-quality-assurance-presentation.pdf.