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Estimation of eye lens doses received by pediatric interventional cardiologists

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ABSTRACT

Maximum $H_p(0.07)$ dose to the eye lens received in a year by the pediatric interventional cardiologists has been estimated. Optically stimulated luminescence dosimeters were placed on the eyes of an anthropomorphic phantom, whose position in the room simulates the most common irradiation conditions. Maximum workload was considered with data collected from procedures performed in the Hospital. None of the maximum values obtained exceed the dose limit of 20 mSv recommended by ICRP.

1. Introduction

The new directive 2013/59 Euratom of 5 December 2013, which covers the April 2011 statement of the International Commission on Radiological Protection (ICRP), reduces the equivalent dose limit for the eye lens in occupational exposure, in planned exposure situations, to 20 mSv per year, averaged over five year periods, so 50 mSv in a single year are not exceeded. In interventional cardiology procedures (IC) performed with adult patients, eye lens doses are generally monitored for workloads higher than 400 procedures per year, since in this case the limit can be easily exceeded if goggles are not used (Vanhavere et al., 2011). Although in pediatric interventional cardiology lower doses to patients than in adults have been reported (Martín et al., 2003), and therefore lower doses in the exposed workers eye lens are expected, the literature detailing the operational implications of the application of this limit in pediatric patients is virtually nonexistent. There are different dosimetric methods for estimating the dose to the lens, from personal dosimeters placed over the lead apron to thermoluminescent (TLD) dosimeters calibrated in terms of $H_p(3)$ located at eye level (Bilski et al., 2011). This paper aims to estimate through simulations with dummy and Optically Stimulated Luminescence Dosimeters (OSLDs) the maximum cumulative lens dose in a year in terms of $H_p(0.07)$. Although the operational quantity recommended to monitor eye lens dose is $H_p(3)$ (ICRU Report no. 51, 1993), Behrens et al. (2012) and Annex B of ICRP 103 (2012) suggest that in the photon energy considered in this paper $H_p(0.07)$ is sufficiently reliable.

The OSLDs have been recently introduced as an alternative to traditional TLD dosimetry. The first time that Optically Stimulated Luminescence (OSL) dosimetry was proposed was in 1985, as a new technique for sediments dating (Huntley et al., 1985). The marketing of OSLDs based on aluminum oxide was started in 1998 by Landauer Inc. (OSL Dosimetry online, 2007), and their use in diagnostic radiology goes back to 2005 (Aznar, 2005). Although still incipient, the use of OSLDs in medicine is growing because it has advantages such as high sensitivity, fast reading and the ability to read successive times the absorbed dose (Jursinic, 2007; Yukihara and Mckeever, 2008; Al-Senan and Hatab, 2011; Chester, 2009). Moreover, its high dependence on energy in the range of radiology can be corrected (Al-Senan and Hatab, 2011). These features make these dosimeters particularly interesting in the field of radiation protection. In pediatric interventional cardiologists eye lens dose measurement, some of these features may be particularly useful, such as high sensitivity, since patients have a high morphological variability, with generally smaller thickness than in procedures performed in adults. Usually longer interventions are observed, and this procedures are performed using equipment adjusted to low dose rates (Vano et al., 2008).

First, this paper presents the results of the most relevant tests performed to validate the OSL dosimetry equipment in the energy range of radiology. Results concerning the stability, reproducibility and linearity of the reader system and the angular and energy dependence of OSLDs are presented. Second, the dose rates measured with the OSLDs placed over the eyes of a high standard

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anthropomorphic phantom positioned in the room in the most common conditions are shown. Irradiation has been performed over a PMMA phantom that simulates a pediatric patient. Beams corresponding to the high dose fluoroscopy and acquisition are used. Finally, $H_p(0.07)$ for a year is estimated from the equivalent dose rate in the eyes of the phantom and the fluoroscopy and acquisition times of interventional cardiology procedures performed during one year.

2. Materials and methods

2.1. Dosimeters and X-ray equipment

The dosimetry equipment used consists of a set of photoluminiscent rounded crystal (Al_2O_3:C) dosimeters embedded in a squared plastic protective capsule, (screened nanodots, Landauer Inc., see Fig. 1), a reader (MicroStar, Landauer Inc.), an automatic eraser (Pocket Inlight Annealer, Landauer Inc.) and an external PC with custom software. Action is taken immediately and allows the possibility of repeated readings. During the reading process, a set of light emitting diodes (LED) continuously stimulate the detector crystal and the emitted light is detected by a photomultiplier tube (PMT). The light intensity released during optical stimulation is directly proportional to the absorbed radiation dose.

To study the dosimetry system reproducibility, a conventional radiology equipment Philips Digital Diagnost was used. The remaining measurements performed, as well as simulations with Rando anthropomorphic phantom, were performed in the pediatric interventional cardiology room, with a Siemens Artis Zee Biplane. The generator is a Polydoros A 100 model (Siemens), and the X-ray tube is a Megalix CAT Plus model (Siemens), three focused (0.3, 0.6 and 1 mm), with a 12.5° Tungsten–Rhenium anode and 2.5 mm Al inherent filtration. The equipment has four image modalities (i.e. four quality of beams): high-dose fluoroscopy FL+ (more usual filtration of 0.3 mm Cu), normal fluoroscopy FL (filtration of 0.6 mm Cu), low-dose fluoroscopy Fl− (filtration of 0.9 mm Cu), and acquisition (or cine, unfiltered). Usually, all fluoroscopy beams are set to 3 pulses/s. All experimental measurements were performed in the Department of Radiology at the Hospital Universitario La Paz, Madrid. The statistical analyzes performed in this work were made using the Wolfram Mathematica v.8 program. A p value less than 0.05 as statistically significant has been considered.

2.2. Reading process, stability and reader calibration

The reading process consisted of reading five times each OSLD, and taking the average of the last four readings (corrected signal loss by reading or depletion) as the best estimate of the cumulative dose in the dosimeter after any irradiation. Dosimeters were read within a maximum 24 h after irradiation, so it was not considered necessary to take into account neither the effect of environmental background radiation nor signal fading effect. Before each measurement, dosimeters were deleted using the Landauer eraser, for 20 s (Landauer, 2012). The set of nanodots used presented a lower detection limit of 16 μSv. Accumulated counts during irradiation, C, were considered as accounts read after exposure minus the residual counts obtained after deleting for 20 s.

Fig. 1. Nanodot dosimeters. At the right, the rounded photoluminescent crystal is shown.

The stability of the reader was tested every day that it was used to analyze the response of the PMT after undergoing a series of external stimuli: a small sample encapsulated ^{14}C (PMT counts), a set of LEDs (LED counts) and no stimulus present (DRK counts). It is considered that the system is stable if none of the responses exceeds mean and variance Control Limits (CL) (Oakland, 2003).

Reader calibration was performed using calibration dosimeters set provided by Landauer, irradiated with beam quality RQR6 (80 kVp, average energy of 44 keV and HVL of 3.01 mm Al) at different doses, in terms of $H_p(0.07)$.

2.3. Dosimetry system validation

The ability of OSL dosimetry system for dose measurements in eye lens was assesed, evaluating reproducibility, signal loss by repeated readings and dose linearity, as well as angular and energy dependence of nanodots on the qualities of beams most commonly used in clinical practice. The reproducibility of measurements were compared with readings provided by an ionization chamber, and evaluated using the CoV of the resulting readings average of 10 consecutive irradiation–erase cycles. To estimate the signal loss in reading, ten dosimeters previously deleted were irradiated at the same doses, and read eleven times consecutively. Dose linearity was estimated by performing a linear regression test of a nanodot response at increasing doses. To assess the maximum angular dependence of the nanodots in the field of scattered radiation, for the energies considered, eighteen nanodots were irradiated varying successively the position by 90° in each the spatial direction, with respect to the reference position of zero degrees. The response energy dependence of the nanodots was evaluated according to the procedure followed by Al-Senan and Hatab (2011), except that a backscatter material was used. The mean energies and half-value layers (HVL) of fluoroscopy and acquisition beams have been calculated using a filtered X-ray spectra generated with the software SPEKTR (Siewerdsen et al., 2004), and have been compared with the effective energies estimated from the mass attenuation coefficient of Al (Birch et al., 1979) and with the measured HVL from a beam analyzer, with good agreement. The doses measured with the ionization chamber were corrected for beam quality factors provided by the manufacturer, and the most appropriate calibration coefficient was used in each case, according to the calibration certificate. For the calculation of the correction factor, the energy distribution of the spectrum of the scattered and direct radiation were assumed to be similar, as neither ceiling screens nor goggles, that can harden the spectrum, are considered (Duch et al., 2013).

2.4. Phantom measurements

To estimate the accumulated equivalent dose in a year in the lens of an interventional pediatric cardiologist, three nanodots were placed in each eye of a Rando anthropomorphic phantom, as shown in Fig. 2. Phantom was positioned so that the eyes were 160 cm from the floor, which corresponds to an approximate height of 170 cm. As material dispersion, 10 cm PMMA positioned between the focus and the image detector was used. The anthropomorphic phantom was placed next to the examination table, facing the display screen and diagonally to PMMA (see Fig. 3), which corresponds to interventional