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Original paper

Eye lens radiation exposure of the medical staff performing interventional urology procedures with an over-couch X-ray tube

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ABSTRACT

The purpose of this work was to estimate the eye lens radiation exposure of the medical staff during interventional urology procedures. The measurements were carried out for six medical staff members performing 33 fluoroscopically-guided procedures. All procedures were performed with the X-ray tube positioned over the couch. The dose equivalents ($H_p(0.07)$) were measured at the eye level using optically stimulated luminescent (OSL) dosimeters and at the chest level with OSL dosimeters placed over the protective apron. The ratio of the dose measured close to the eye lens and on the chest was determined. The annual eye lens dose was estimated based on the workload in the service. For the physician and the instrumentalist nurse, the eye to chest dose ratios were 0.9 ± 0.4 and 2.6 ± 1.6 ($k = 2$), respectively. The average doses per procedure received by the eye lens were $78 \pm 24\,\mu$Sv and $38 \pm 18\,\mu$Sv, respectively. The eye lens dose per DAP was $8.4 \pm 17.5\,\mu$Sv/(Gy·cm^2) for the physician and $4.1 \pm 8.7\,\mu$Sv/(Gy·cm^2) for the instrumentalist nurse. The results indicate that the eye lens to chest dose ratio greatly varies according to the staff function and that the dose equivalent measured by the personal dosimeter worn on the chest may underestimate the eye lens dose of some medical staff members.

1. Introduction

In the last decade, eye lens exposure has become a major concern in radiation protection, most notably in the field of medical imaging. Follow-up studies show that the radiation-induced cataract incidence is statistically significant for certain categories of medical professionals [1,2]. In 2011, the International Commission on Radiological Protection (ICRP) revised the lifetime eye lens dose (ELD) threshold for radio-induced cataract. Due to the pathology manifestation at doses lower than the previously considered dose limits, the threshold was set to 0.5 Sv for acute and fractioned exposure. Consequently, the ICRP recommended a drastic decrease of the annual ELD limit from 150 mSv/year to 20 mSv/year [3]. In Switzerland, the revision of the Radiological Protection Ordinance, entering into force in 2018, will adopt this new limit. Most probably, the ELD will be indirectly assessed from the dose equivalent quantity $H_p(0.07)$ measured by an over-apron routine surveillance dosimeter worn on the chest [4].

So far, the majority of studies surveying the ELD were performed in interventional cardiology (IC) and interventional radiology (IR) [5,6] as well as in laboratory conditions on anthropomorphic phantoms [7,8]. According to the ICRP Publication 117, fluoroscopy is becoming a wide spread technique in specialties other than IC and IR, e.g. urology, vascular surgery, orthopaedics etc. [9], where healthcare professionals may not be fully aware of the risk related to ionising radiations and/or less equipped in terms or radiation protection means [10,11]. This is likely to result in a non-optimised radiation protection in these specialties, and thus in a higher exposure of medical staff and patient. For this reason, there is a great need to investigate personnel eye lens exposure during fluoroscopically-guided procedures in specialties other than IC and IR. In urology, the ELD was previously measured [12–21], yet there is a lack of data concerning the relationship between ELD and doses retrieved from above-apron surveillance measurements, especially in the case of over-couch X-ray tube imaging systems (AP projections). The determination of the eye to chest dose ratio is crucial in assessing the ELD when only dose measurements from the personal dosimeter are available.

This study presents the evaluation of eye lens exposure of the medical staff performing standard interventional urology procedures with over-couch tube geometry. The aim of this study was to measure the ELD per procedure and to compare it with the literature values from under-couch systems in urology and other medical specialties. For this purpose, the medical staff was equipped with optically stimulated

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luminescent (OSL) dosimeters. Dosimeters were assigned to specific staff functions to minimise the impact of factors such as the surgeon experience and the fluoroscopy settings of the installation. We assessed the relationship between eye lens and chest doses to determine whether the extrapolation of the ELD from a measurement performed by a routine personal dosimeter provides conservative results. The probability of exceeding the ELD yearly limit in the urology service is also discussed in order to determine if additional radiation protection measures should be taken.

2. Materials and methods

2.1. Dosimeters

This study was conducted using optically stimulated luminescent dosimeters (OSLDs). Two models of OSLDs (Landauer, USA) were used: the nanoDot™ and the InLight®, both containing carbon-doped Al_2O_3 as detector material. NanoDot dosimeters consist of a plastic holder of $10 \times 10 \times 2\ mm^3$ with a disc-like pellet of 0.3 mm thickness and 5 mm diameter [22]. InLight dosimeters contain four Al_2O_3 disc-like pellets with a diameter of 5 mm, enclosed in a plastic holder of $49 \times 23 \times 5\ mm^3$. Three pellets are filtered with materials of different thickness and density to reproduce various tissue depths and dose equivalents ($H_p(10)$, $H_p(3)$, $H_p(0.07)$) [23]. The fourth pellet is covered by a thin layer of protective plastic and allows for the detection of beta particles.

The reading of both dosimeter models was performed using the Landauer MicroStar reader. Each dosimeter was read three times to reduce the uncertainty of the dosimeter readout. The dosimeters' annealing was performed with the Landauer Pocket Annealer that depletes the dosimetric traps by illuminating the detector material with a blue LED during 60 s.

2.2. Dose calculation

The two OSLDs models were calibrated in terms of $H_p(10)$ on a water-filled slab phantom ($30 \times 30 \times 15\ cm^3$) according to the ISO 4037 standard [24], using a ^{137}Cs reference beam. The dose equivalent $H_p(10)$ was calculated from the raw photomultiplier tube counts using the conversion factor from the system calibration and the dosimeters' sensitivity provided by the manufacturer, following Eq. (1):

$$H_p(10) = CF^{-1} \sum_{j=1}^{N} \left[\frac{(R_j - R_{r,j})}{S \cdot N} - \frac{(R_j^{nat} - R_{r,j}^{nat})}{S^{nat} \cdot N} \right] \quad (1)$$

where CF is the conversion factor between PM counts and dose equivalent, S and S^{nat} are the sensitivities of the dosimeters used for the dose and natural background measurements, R_j is the raw PM counts of the pellet j, R_r is the PM counts corresponding to the residual pellet signal, R^{nat} is the PM counts due to the natural background dose and N is the number of pellets of the considered dosimeter model ($N = 1$ for nanoDot, $N = 4$ for InLight). The personal dose equivalent at depth d for a radiation quality Q, $H_p(d;Q)$, was calculated using Eq. (2):

$$H_p(d;Q) = f_E \cdot H_p(10) \cdot \frac{h_p(d;Q)}{h_p(10;^{137}Cs)} = H_p(10;^{137}Cs) \cdot \frac{h_p(d;Q)}{h_p(10;^{137}Cs)} \quad (2)$$

where f_E is the energy correction factor of the dosimeter response for an irradiation quality Q with respect to ^{137}Cs [25], $h_p(10;^{137}Cs)$ is the conversion factor relating dose equivalent (at a depth d with respect to ^{137}Cs) to the air kerma and $h_p(d;Q)$ is the conversion factor allowing to relate the air kerma to the dose equivalent at a depth d for the original radiation quality Q [24].

The signal ratios from the four InLight pellets were used to determine the photon energy in the diffused field to which the medical staff was exposed. Photon energies of 30–40 keV and an average energy of 36 ± 6 keV were found. All OSLD doses were corrected by applying energy correction factors f_E specific to the determined mean energy for each medical staff member.

All the doses were then expressed in terms of an ISO 4037 N-60 quality beam [24], as its average energy (48 keV) is close to the one found in this study and provides more conservative results with respect to a N-40 quality beam (average energy: 33 keV).

No angular correction of the dosimeter response was performed, since the position of the personnel during fluoroscopy was greatly varying and accurate corrections were difficult to apply. The angular response of the dosimeters (up to 10% dose underestimation at angles of 60° for a photon energy of 40 keV [25]) was included in the uncertainty estimation. The OSLDs' detection limit was found to be 30 μSv.

Recently, conversion factors from air kerma to $H_p(3)$ were published [26–28]. Nevertheless, in the present study, all dose values are reported in terms of $H_p(0.07)$. This quantity is considered by the ICRP 103 to provide reliable results for ELD monitoring [29], especially in the energy range of scattered photons from fluoroscopy [30] and is foreseen as the reference quantity for the ELD extrapolation in the revision of the Swiss Radiological Protection Ordinance.

2.3. Uncertainties

All uncertainties are given with a coverage factor of $k = 2$. We considered uncertainties on the dosimeter sensitivity (5%), the conversion factor (3%), the air kerma-dose equivalent conversion factors (4%) and the energy correction factor (between 15% and 50%). Latter is particularly significant due to the strong energy dependence of Al_2OAl_3 in the investigated energy range (20–100 keV). An additional uncertainty of 5%, valid for angles up to 60°, was considered in order to take into account the dosimeters' angular response. By adding all individual (independent) uncertainty components in quadrature according to the law of uncertainty propagation, we obtained a combined relative uncertainty of approximately 40% for a dose measurement.

2.4. Imaging systems

The imaging systems used in the urology service are an Opus II Urology Information Management System (Dornier MedTech, Germany) and a Uroskop Omnia (Siemens Healthcare, Germany). Both fluoroscopy units are provided with an automatic exposure control (AEC) that adjusts exposure factors such as current and tube voltage depending on the patient's geometry. These fluoroscopy units present an over-couch geometry, i.e. with the X-ray tube above and the image intensifier below the patient table (AP projection). This configuration ensures a reduced distance between the patient and the detector, a greater space for patient's accommodation and a better operator's mobility [18] at the cost of higher exposure of the medical staff [31].

2.5. Radiation protection means

The medical staff always uses protective aprons (0.25 or 0.35 mm lead-equivalent at 100 kV, Scanflex Medical AB, Sweden) with thyroid shields. Other personal radiation protection means, such as lead glasses without side protection, are available but rarely worn. During laser lithotripsy, the use of laser safety glasses prevents the personnel from wearing radiation protection goggles. No collective radiation protection means such as ceiling suspended shields or lead curtains are available in this service. The lack of collective radiation protection means is common during urology procedures [12,15–20].

2.6. Dosimetric surveillance of the personnel

Routine interventional urology procedures were monitored at the