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Dose estimation of eye lens for interventional procedures in diagnosis

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ABSTRACT

The International Commission on Radiological Protection (ICRP) recommended that the equivalent dose limit for the lens of the eye be decreased from 150 mSv/y (ICRP, 2007) to 20 mSv/y averaged over five years (ICRP, 2011). How to accurately measure the eye-lens dose has, therefore, been an issue of interest recently. Interventional radiologists are at a higher risk of radiation-induced eye injury, such as cataracts, than all other occupational radiation workers. The main objective of this study is to investigate the relationship between the doses to the eye lenses of interventional radiologists measured by different commercial eye-lens dosimeters. This study measured a reference eye-lens dose, which involved placing thermoluminescent dosimeter (TLD) chips at the surface of the eye of the Rando Phantom, and the TLD chips were covered by a 3-mm-thick tissue-equivalent bolus. Commercial eye-lens dosimeters, such as a headband dosimeter and standard personnel dose badges, were placed at the positions recommended by the manufacturers. The results show that the personnel dose badge is not an appropriate dosimeter for evaluating eye-lens dose. Dose deviations for different dosimeters are discussed and presented in this study.

1. Introduction

A number of recent studies have concerned the problem of how to accurately measure eye-lens doses as the International Commission on Radiological Protection (ICRP) recently recommended a new equivalent dose limit for the eye lens (Carinou et al., 2015). The equivalent dose limit is now 20 mSv in a year, averaged over 5 years, with no single year exceeding 50 mSv (ICRP, 2011). The previous recommended equivalent dose limit announced in ICRP Publication 103 was 150 mSv per year (ICRP, 2007). In general, interventional radiologists are at a higher risk of radiation-induced eye injury, such as cataracts, than all other occupational radiation workers, because they have to stand close to patients and x-ray sources during the fluoroscopic procedure (Sun et al., 2013).

The current equivalent dose limit for the eye lens announced by the Atomic Energy Council of Taiwan is 150 mSv per year. Therefore, the issue of the occupational eye lens dose has still been neglected due to the high dose limit. Additionally, the typically routine dosimeter for the personnel dose monitoring of interventional radiologists is a personnel dose badge worn on the trunk (chest level) and inside a lead apron. However, the eye and chest levels are different, which has raised doubts regarding the accuracy of measurements of the true lens dose (Farah et al., 2013).

The main objective of this study is to investigate the relationship between the doses to the eye lenses of interventional radiologists measured by different dosimeters.

2. Methods and materials

2.1. Types of dosimeters

Three different types of dosimeters were used in this study and are introduced in the following.

2.1.1. TLD-100H chips

TLD-100H chips made of LiF: Mg,Cu,P (Thermo Electron Corporation, USA) were used. All of the TLD-100Hs were annealed at 240 °C for 10 min before being used to monitor the exposure doses. After exposure, the TLD signals were read by a Harshaw Model 3500 reader (Thermo Scientific Harshaw). The read-out cycle for the TLD-100H chips included a linear heating rate of 10 °C s^{-1} for room temperature to 240 °C (Thermo Electron Corporation, 2002). The TLD chips were calibrated with a standard ^{137}Cs source at the Dose Calibration Laboratory (DCL) of National Tsing Hua University in Taiwan. The DCL is an accredited calibration laboratory recognized by the Taiwan Accreditation Foundation (TAF). The relationship between

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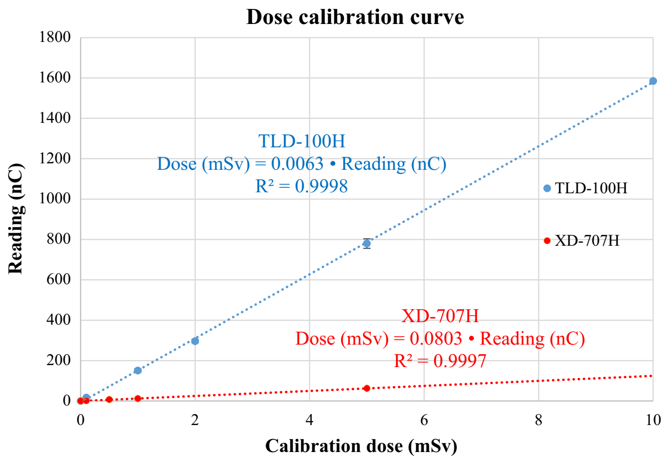

Fig. 1. Dose calibration curves of TLD-100H chips and XD-707H (headband eye dosimeter).

the dose and reading is shown in Fig. 1. The reading (in the unit of nC) to dose (in the unit of mSv) conversion factor was 0.0063 (mSv/nC).

2.1.2. Headband eye dosimeter

The headband eye dosimeter consisted of one TLD-700H TLD element (EXTRAD type of XD-707H, Harshaw™) and a 1.5-mm-thick PTFE filter, which is equivalent to 3-mm-thick tissue. The TLD element was enclosed behind the PTFE filter in a sealed PVC pocket. The headband was fastened by means of Velcro™ strips, which could be trimmed to length (Gilvin et al., 2013). The TLD signals were read by a Harshaw Model 4500 Reader (Thermo Scientific Harshaw) and read again at least five times until the readings were as lowest as annealing it. The read-out cycle for the XD-707H TLDs included a heating rate of 10 °C s^{-1} to heat TLD from room temperature to 240 °C for 30 s and then 240 °C for 10 s of annealing. The dose calibrations of the TLD chips were performed with a standard ^{137}Cs source at the DCL. The relationship between the dose and TLD reading is also shown in Fig. 1. The reading (nC) to dose (mSv) conversion factor was 0.0803 (mSv/nC).

2.1.3. Personnel dose badges

The personnel dose badges used in this study were optically stimulated luminescence dosimeters (OSLD). The dosimeters were composed of four chips, which were covered by different thickness of metal and plastic filters to stimulate the equivalent deep, eye-lens, and shallow dose. The dose signals were read by an automatic reader (InLight® Auto 200 Reader, Landauer). The applicability of measuring eye-lens dose using personnel dose badges is discussed in the results section of this paper.

2.2. Experimental design

The clinical measurements were performed on a digital angiography system (Bransist Safire VC17, Shimadzu) at Linkou Chang Gung Memorial Hospital. The different types of dosimeters mentioned above and different exposure situations were applied for the measurements. A Rando phantom (Alderson Research Labs, USA), which represented the radiologist, and an anthropomorphic phantom with a head, thorax, and pelvis (manufactured by Radiologic Support Device Inc.), which was positioned on the operating table to simulate a patient, were used in this study. The experimental setup is shown in Fig. 2.

This study measured the eye-lens doses by placing thermoluminescent dosimeter (TLD-100H) chips on the surface of the eyes of the Rando phantom and covered these TLD chips with a tissue-equivalent 3-mm-thick bolus (MTCB403, CIVCO Medical Solutions, Iowa, USA). Commercial dosimeters used for assessing the eye-lens doses, such as

Fig. 2. The setup of the experiment.

personnel dose badges and headband eye dosimeters, were placed at the positions on the phantom body recommended by the manufacturers. The personnel dose badges were placed on the different positions on the Rando phantom, including positions inside and outside a lead apron at the chest and collar levels. The headband dosimeter was placed 3.5 cm above the eye level on the head of the Rando phantom. The setting positions of the dosimeters are shown in Fig. 3.

The different exposure situations according to clinical examination were divided into three parts: abdomen, head, with C-arm (AP view) and head with Ω-arm (LAT view). The assumed exposure time of each experiment is 10 min, which is the average examination time for a fluoroscopic procedure for the abdomen, such as Transarterial Chemoembolization (TACE) of liver cancer, antegrade venography, and a Peripherally Inserted Central Catheter (PICC). A fluoroscopic procedure for the head, such as cerebral aneurysm coiling and the treatment of intracranial artery stenosis, usually takes a long time (from 30 to 90 min). The exposure time is also 10 min for head conditions in this study for the purpose of better comparison with abdomen conditions. The exposure parameters of different exposure situations are shown in Table 1. Additionally, radiation protection for the eyes, such as wearing lead glasses, is important for radiologists (Vanhavere et al., 2011). Therefore, the dose comparison between with and without wearing lead glasses was also discussed in the results. The thickness of the lead glasses used in this study was 0.07 mm-Pb.

All of the measurements for the TLD-100H chips in every different exposure situation were repeated at least twice, and there were five TLD-100H chips on one eye each time. For the headband eye dosimeter, all of the measurements in every different exposure situation were repeated at least three times and the final value was the average of these measurements. For personnel dose badges, the measurements for different position and exposure situations were repeated twice and the read-outs were repeated four times. The doses for different positions and exposure situations were the average results.

2.3. TLD responses calculated by Monte Carlo simulations

To discuss the response influence of the different geometry properties (thickness, shape, and volume) between TLD-100H and TLD-700H (XD-707H from the headband dosimeter), a simple simulation calculated using the MCNP5 code (MCNP5, 2005) was performed. The geometries of stimulation for calculating the TLD responses are shown in Fig. 4. All calculations were performed using different mono-energetic photon values, from 1 to 662 keV. The relative responses between TLDs and air for TLD-100H and TLD-700H are given by Eqs.