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A method to reduce patient's eye lens dose in neuro-interventional radiology procedures

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HIGHLIGHTS

- The eye protector can considerably reduce the patient's eye lens dose during neuro-interventional procedures.
- This protector does not significantly perturb the fluoroscopy image and was completely invisible on the acquisition image due to image subtraction.
- The eye protector does not significantly change the exposure parameters (kV and mAs).

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ABSTRACT

Complex and prolonged neuro-interventional radiology procedures using the biplane angiography system increase the patient's risk of radiation-induced cataract. Physical collimation is the most effective way of reducing the radiation dose to the patient's eye lens, but in instances where collimation is not possible, an attenuator may be useful in protecting the eyes. In this study, an eye lens protector was designed and fabricated to reduce the radiation dose to the patients' eye lens during neuro-interventional procedures. The eye protector was characterised before being tested on its effectiveness in a simulated aneurysm procedure on an anthropomorphic phantom. Effects on the automatic dose rate control (ADRC) and image quality are also evaluated. The eye protector reduced the radiation dose by up to 62.1% at the eye lens. The eye protector is faintly visible in the fluoroscopy images and increased the tube current by a maximum of 3.7%. It is completely invisible in the acquisition mode and does not interfere with the clinical procedure. The eye protector placed within the radiation field of view was able to reduce the radiation dose to the eye lens by direct radiation beam of the lateral x-ray tube with minimal effect on the ADRC system.

1. Introduction

Eye lens is one of the radiosensitive organs in human body (Durchschlag et al., 1999). Recent epidemiology studies had shown that radiation-induced cataracts could occur at low levels of ionising radiation exposure (Worgul et al., 2007; Shore et al., 2010; Stewart et al., 2012). Among the different radiological modalities, computed-tomography (CT) scans of the head and neck (Siddle et al., 1990; Moulin et al., 1996; Niu et al., 2010) and fluoroscopy-guided neuro-interventional procedure (Ilgit et al., 2000; Moritake et al., 2008; Sandborg et al., 2010; Safari et al., 2016a) had been observed to pose a higher risk of cataract formation, especially among those with visual impairment, young patients, and patients who required multiple CT scans or prolonged neuro-interventions. For CT scans, different techniques had been suggested to reduce the eye-lens dose, such as positioning the eyes outside the scanning region, angling of the gantry along the supraorbital meatal line (Heaney and Norvill, 2006; Matsubara et al., 2011) and using bismuth-impregnated latex shields (Heaney and Norvill, 2006; Hopper et al., 2001).

Fluoroscopy-guided neuro-interventional procedure is used to visualise the arterial system for diagnosis and treatment. Complex procedures involving prolonged radiation exposure might exceed the threshold dose for cataract formation. These procedures are mainly performed under biplane fluoroscopy units, whereby the lateral x-ray tube is generally utilised at one side of patient's head almost perpendicular to the patient's eye. A previous study (Safari et al. 2016b) showed that 93% of the lateral tube radiation dose

Abbreviations: ADRC, Automatic Dose Rate Control; KAP, Kerma-Area-Product; RAO, Right Anterior Oblique; LAO, Left Anterior Oblique; EDS, Energy-Dispersive x-ray Spectroscopy; PDD, Percentage-Depth-Dose; DSA, Digital Subtraction Angiography; fps, frames per second

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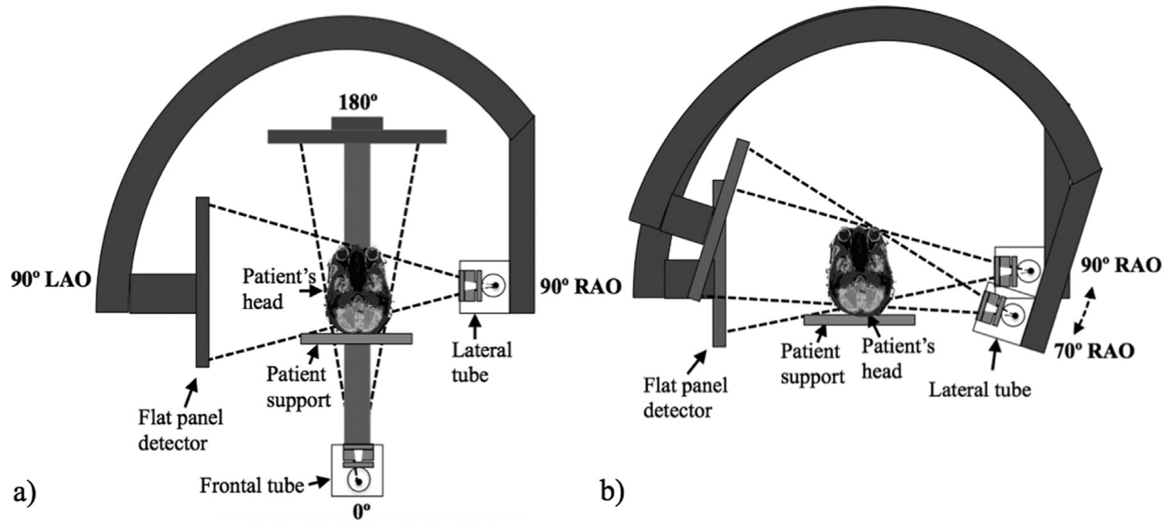

Fig. 1. Diagram of a Philips Allura Xper FD20/20® machine, a) positioning of the frontal and lateral tube, as well as patient's head and b) the most common lateral tube exposure directions (70° RAO to 90° RAO).

(quantified as Kerma-Area-Product) was delivered when the tubes were positioned between 70° and 90° of the right anterior oblique (RAO) (Fig. 1). At these angles, the patient's left eye was directly exposed to the primary radiation beam. While it is almost impossible to collimate the frontal tube to exclude the eye from the radiation field of view, collimation of the lateral tube exposure field of view is possible. Collimation of the lateral tube would shield the eye from direct radiation beams. However, in some situations where physical collimation to exclude the eye was not possible, an attenuator might be useful in reducing the radiation dose of the primary beam.

To the best of authors' knowledge, to date there is no in-field radiation protector for patient eye lens during neuro-interventional procedures. The purpose of this study was to design and fabricate an eye protector to reduce the patient's eye lens dose, while does not interfere with the clinical procedure. The eye protector was studied in terms of its radiation attenuation properties and its effects on image quality and exposure parameters.

2. Materials and methods

2.1. Eye protector

A custom-made eye protector was fabricated using polyurethane rubber (VytaFlex®40, Smooth-On, Inc., Easton, PA. USA). The polyurethane rubber due to its low viscosity can be easily poured into different mould shapes and also remains pliable without any structural change under the stress. It is very light and its attenuation properties can be simply modified by adding high and low density materials, like $CaCO_3$ and phenolic microspheres, respectively (Jones et al., 2003). The mixture of the 10 g polyurethane with 1.5 g $CaCO_3$ was stirred until evenly mixed and left to set in a 50 mm diameter cylinder mould and the resulting eye protector was 16 mm thick. The elemental composition of the polyurethane rubber was analysed using a Scanning Electron Microscope (Quanta FEG 650, FEI, Hillsboro, OR, USA) attached to an Energy-Dispersive x-ray Spectroscopy (EDS) analyser. The physical density of the eye protector was measured based on the theory of buoyant force using an analytical balance (Sartorius BA110S, Gottingen, Germany). The volume of the eye protector medium was defined as the ratio of the density of the substance to the density of water (with temperature of 4 °C). The attenuation properties of the eye protector were calculated theoretically. Total mass-attenuation coefficient of the material for various photon energies (15–80 keV) was derived from the XCOM photon cross-section database (National Institute of Standards and Technology, 2010). The x-ray spectrum for different fluoroscopy and acquisition modes of a Philips Allura Xper FD20/20® unit (Philips Healthcare, Best, The Netherlands) was calculated using the SpekCalc x-ray spectrum generator programme (Institute of Cancer Research London, UK). The SpekCalc x-ray spectrum generator is a software programme that can take the x-ray tube specifications, like tube potential and anode angle, and produce an energy spectrum of the generated x-rays.

To evaluate the radiation attenuation properties of this material, the percentage depth dose (PDD) response was measured using the Philips Allura Xper FD20/20® biplane system. Square polyurethane rubber slabs (20 cm × 20 cm) were fabricated with different thicknesses for this measurement. The PDD responses were measured using a 0.055 cm^3 Markus parallel plate ion chamber (model 23343, PTW, Freiburg, Germany). The Markus chamber was placed inside a special slot within a solid water slab (Gammex 457, Gammex, Middleton, WI) and 12 cm of the solid water phantom was used as backscattering material. The polyurethane slabs were positioned 80 cm away from the focal spot and exposed using 80 kVp (acquisition mode, 3 frame per second (3 fps)) with a field size of 10 cm × 10 cm (Fig. 2). The PDD curve was obtained by normalising the Markus chamber responses at different depths (from 1 mm to 30 mm) of the eye protector slabs to its response at the surface of the solid water phantom. Our recent study on 58 clinical neuro-interventional procedures revealed that the most frequent tube energy and used frame rate during acquisition imaging technique were 80 kVp (52.4% of all DSA exposures) and 3 fps (contributing to 50.1% of all DSA exposures) (Safari et al., 2016b).

2.2. Phantom study

The exposure parameters of a clinical aneurysm procedure were recorded and the procedure was replayed and simulated onto an adult female anthropomorphic phantom (ATOM, CIRS, Norfolk, VA). The effects of the eye protector on the radiation dose to the eye lens position and dose distribution over the head and eyelid region were studied using the Gafchromic® film (XR-RV3, ISP, Wayne, NJ). The Gafchromic® XR-RV3 is a radiochromic film particularly designed for radiation dosimetry in interventional fluoroscopy procedures. The XR-RV3 is a reflective-type film and