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Modeling and design of a class of hybrid bistable symmetric laminates with cantilever boundary configuration

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Addressing the efficiency of X-ray protective eyewear: proposal for the introduction of a new comprehensive parameter, the Eye Protection Effectiveness (EPE)

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Abstract

Radioprotection of the eye lens of medical staff involved in Surgical procedures is a subject of international debates since ICRP recommended, on 2011, a lower equivalent dose limit for the lens of the eye. In this work we address the effectiveness of different models of X-ray protective eyewear by relating actual dosimetry measurements to an ad hoc developed mathematical model, in order to disentangle the contribution of geometrical factors and shield capabilities. Phantom irradiation was carried out in fixed exposure conditions in angiographic room: we found that measured Dose Reduction Factors (DRF) strongly depend on the ergonomics of the investigated eyewear. Actually a very poor DRF was observed in the case of a glass model in spite of its high nominal attenuation, whereas a protective tool with low shielding capabilities such a visor resulted much more effective as a consequence of is shape (i.e. extended geometric protection of the eye lens). Our work highlights the need of the introduction of a specific parameter to quantify the effectiveness of the protection tools and able to predict their DRF by taking into account the geometry of the clinical condition of exposure. Aiming at making steps forward the standardization of the guidelines concerning the features of eye protective tools, we developed a simple mathematical model describing the eye lens irradiation geometry which allows the introduction, for each eyewear, of a comprehensive parameter, the Eye Protection Effectiveness (EPE), that, for any defined clinical irradiation condition and glass shielding capabilities and shape, defines the overall effective X-ray protection of the eyewear.

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1. Introduction

The medical research in the last two decades brought to new awareness and knowledge regarding the effect of ionizing radiation on the eye lens, one of the most radiosensitive human tissue. As a consequence the International Commission for Radiological Protection (ICRP) recommended, on 2011, an equivalent dose limit for the lens of the eye of 20 mSv/ year, averaged over defined periods of 5 years, with no single year exceeding 50 mSv [1–5].

Among all the workers exposed to ionizing radiation, the medical staff involved in cardio - vascular and interventional radiology is one of the highest-risk category [6–10]. Moreover interventional procedures guided by x-ray imaging have experienced an important increase in the last years. The ORAMED project ([11],[12]), highlighted the need to monitor routinely the eye lens of the staff involved in radiological interventional procedures. The practical and theoretical issues related to the dose monitoring and to the efficacy of the protection tools are not trivial, because several factors contribute to the overall eye lens dose. The radiation reaching the eyes arises from the radiation field scattered by the patient, with a small contribution given by the radiation diffused within the head of the operators [13]. The eye lens absorbed dose is strongly dependent on the operator distance from the scattering source, orientation of the operator head with respect to the patient, position of the monitor, angle projection of the tube, and exposure parameters, such as KAP, radiation quality and tube voltage [14–19]. The effectiveness of the radioprotection equipment available on the market is under debate in the scientific and medical community, because many studies have shown that the nominal lead equivalent thickness is not the best, or at least not the unique, quantity useful to address protection efficiency. The lack of consideration of geometrical parameters can lead to significant prospective underestimation of lens dose, up to one order of magnitude when the eye lens dose is estimated by means of a dosimeter located directly behind the protective lenses ([11, 20]) since in this case the dosimeter is unable to measure the scattered radiation incoming from below the protective eyewear. The international technical standard concerning the classification and the minimum requirements of protection equipment omits many fundamental aspects [21, 22]: for example, it is unclear whether the shielding materials should be incorporated in the glasses frame or not and what should be the optimum shape in order to guarantee sufficient eye lens coverage; additionally the need of lateral protection, other than front lead lens, is not taken under consideration.

Many works have been published about the effectiveness of the protection equipment for the eyes (lead acrylic visors, lead goggles, ceiling suspended lead screen), which state the influence of geometrical factors, such as shape and fit to the operator morphology, on the overall protection efficacy [14–16, 23–25]. In 2009 Miller et.al [13] published a guideline on radiation protection during fluoroscopically guided procedures, emphasizing the benefit of large lenses and side shields. Nevertheless, still a variety of lead glasses and visor models are present on the market, even though their characterization in terms of protection efficiency is often poor and contradictory. The technical parameter most used in literature to address the protection efficiency is the Dose Reduction Factor (DRF), defined as

$$DRF = 1 - \frac{D_p}{D_a} \tag{1}$$

where D_p and D_a are the dose reaching the eye lens in presence and absence of the protection tool, respectively. Many authors calculated DRFs for several goggles models and for different projection angles and operators positions, [20, 26–29]. However, since the DRF is dependent on the geometric conditions of exposure, these methods seem not applicable to all clinical situations and glasses shapes, and a generalized approach to the problem is still far from being achieved.

In this context, our work tries to bring clarity about the variables that affect the efficiency of different kind of X-ray eye-protection tools. To this purpose we developed a mathematical model, that includes geometrical factors and lead-equivalent thickness, which was verified experimentally in angio-room for several different eyewear by irradiating an anthropomorphic ATOM Phantom (CIRS) equipped with thermoluminescent dosimeters. The obtained results encouraged us to propone the introduction of a new comprehensive parameter, the Eye Protection Effectiveness (EPE), that, for any defined clinical irradiation condition and glass shielding capabilities and shape, defines its overall effective X-ray protection.

2. Materials and methods

In this work we investigate the protective efficiency of three different models of glasses and a visor. Pictures of the eyewears studied are presented in Fig 1 .

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