Review

Radiation Protection of the Eye Lens in Fluoroscopy-guided Interventional Procedures

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Abstract

The medical staff involved in fluoroscopy-guided procedures are at potential risks of radiation-induced cataract. Therefore, proper monitoring of the lens doses is critical, and radiation protection should be provided to the maximum extent that is reasonably achievable. The collar dosimeter is necessary to avoid underestimation of the lens dose, and the third dosimeter behind the protective eyewear would be helpful for those who are likely to exceed the dose limit. The reduction of the patient doses will correspondingly reduce the staff doses. Proper placement of the ceiling-mounted shields and minimization of the face-to-glass gap are the keys to effective shielding. The optimization of procedures and devices that help maintain a distance from the irradiated area and to prevent the looking-up posture will substantially reduce the lens dose.

Key words: Radiation protection, Eye lens dose, Protective eyewear

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Introduction

The lens of the eye is one of the most radiosensitive tissues in the human body. Radiation exposure causes the characteristic changes in the lens leading to opacification, which can progressively increase with dose toward vision-impairing lesions. In April 2011, the Seoul Statement of the International Commission on Radiological Protection (ICRP) [1] indicated that the equivalent dose limit for the lens from occupational exposure should be lowered to 20 mSv/year on average over defined periods of 5 years with the dose in no single year exceeding 50 mSv. This is because recent epidemiological studies [2-5] demonstrated that the threshold dose for radiation-induced cataracts might be lower than previously estimated. In response to this, ICRP Publication 118 was issued in 2012 [6], and the revised equivalent dose limits for the lens of the eyes were incorporated into the latest safety standards of the International Atomic Energy Agency (IAEA) [7]. Also in Japan, the revised lens equivalent dose limit has been incorporated into laws and regulations, which came into effect in April 2021.

Medical staff involved in fluoroscopy- or computed tomography-guided interventional procedures are at potential risks of exposure to radiation levels that may cause radiation-induced lens opacity. In fact, complex and difficult procedures tend to result in higher doses of exposure. It was reported that the mean lens dose of radiologists from single transarterial chemoembolization (TACE) for hepatocellular carcinoma was 0.204 mSv [8], which means that the lens dose would reach the dose limit of 20 mSv after 98 TACEs per year. The mean operator lens dose per case ranged from 0.019 to 0.800 (median = 0.113) mSv in a literature review of the radiation doses during various procedures, including percutaneous nephrolithotomy, vertebroplasty, orthopedic extremity nailing for the treatment of fractures, biliary tract procedures, transjugular intrahepatic portosystemic shunt creation (TIPS), head/neck endovascular therapeutic procedures, and endoscopic retrograde cholangiopancreatography (ERCP) [9]. A dose survey in Japan for neurovascular interventions revealed that the mean dose of the left eye lens per procedure was 0.088 mGy, or 0.176 mGy if ceiling-mounted

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shields or lead glasses were not used [10]. In fact, more than 2,000 healthcare workers in Japan, mostly physicians, have had their equivalent dose of the lens exceed 20 mSv per year in 2020 [11, 12]. Radiation cataracts are a real possibility; therefore, dosimetry and radiation protection of the eye lenses has become more important than ever.

Dosimetry of the Lens of the Eye

Adequate monitoring is essential for the proper management of the eye dose because both underestimation and overestimation can occur in lens dose monitoring.

Hence, it is recommended to use at least two personal dosimeters during fluoroscopy [13]: one on the chest or abdomen inside the protective apron and the other typically on the neck outside the protective apron. Here, the dose of the neck dosimeter will be used as an estimate of the lens dose. Unfortunately, however, there are some hospitals where only one personal dosimeter is distributed per person, and the dosimeter might be worn inside the protective apron to better estimate the effective dose. In such a case, the single dosimeter will also be used for estimating the lens dose. The transmission of the protective apron is typically between 0.5% and 10% [14, 15]. In a clinical study of percutaneous coronary intervention [16], the ratio of doses outside to inside the protective apron ranged from 7.62 to 60.42, with a median of 19.78. Thus, the lens dose will be underestimated as ˜5% of the proper value, if only one dosimeter inside the protective apron is used.

Importantly, the incorrect and irregular use of personal dosimeters is another cause of underestimation. One study from Spain reported that 36% of interventional radiologists admitted that they forget to use their personal dosimeters for more than 7 days per month [17]. Another study demonstrated that ˜50% of the interventional cardiologists reported that they use personal dosimeters, and only 30% use them regularly [18]. If the dosimeter over the protective apron does not show substantially higher readings than the dosimeter under the apron, it simply indicates that their placements might have occasionally been reversed unknowingly, which will cause an underestimation in the lens dose.

If protective glasses are not worn, a dosimeter outside the protective shield at the collar level can be reasonably used to monitor the lens dose, but if protective glasses are effectively used, the collar dosimeter should correspondingly overestimate the lens dose. Assuming a dose reduction factor (DRF) of 2 for the protective eyewear, the lens dose by the collar dosimeter will be overestimated by a factor of 2. The third dosimeter behind the protective eyewear is expected to monitor the lens doses more accurately than the collar dosimeter as it can reflect the shielding effect of the protective glasses [19-21]. It would be helpful in critical cases, such as the staff who are likely to be exposed to a dose exceeding the limit. Japanese guidelines for radiation safety and dose monitoring of the eye lens recommend the use of the dosimeter behind the protective eyewear for medical staff whose lens dose exceeds 20 mSv per year [22, 23]. Monitoring using three dosimeters would have potential problems regarding reliability on and consistency of the use of the dosimeters, but it could be used for short-term comparison [13].

Radiation Protection of the Lens

Minimizing the dose to the patients

The scatter radiation dose is proportional to the patient dose; therefore, the reduction of the patients' dose will almost always reduce the occupational doses of the medical staff. There are many factors that can reduce patient dose [24]: an increase in the distance between the X-ray tube and the patient, a decrease in the distance between the patient and the detector, reduction of fluoroscopy time, tube current, pulse rate of fluoroscopy, frame rate of acquisition, number of acquisition runs, prevention of oblique or lateral projection overuse, and utilization of collimation and last image hold function. Specific methods and techniques for reducing patient dose will be discussed in another article in this issue.

Ceiling-mounted shielding screen

One of the most important parts of lens protection is the proper use of shielding, especially ceiling-mounted screens and protective eyewear with lead glass. Properly placed ceiling-mounted shields will provide higher dose reduction over a wider area than lead glasses [25]. For instance, it has been reported that ceiling-mounted shields can reduce the dose to the head by factors of 4-10 in phantom studies and by factors of 2-7 even in clinical settings [26]. Lead drapes attached to the bottom edge of the ceiling-mounted shield would help fill gaps between the shield and the body of the patient. Practical dose reduction by ceiling-mounted shields depends on how effectively positioned they are. The shield should be placed between the head of the operator and the irradiated area of the patient's body, i.e., the operator must be able to see the irradiated area through the shield. Moreover, the shield should be placed just above the body of the patient so that the gap is maximally as small as possible. Every time the operator's position or the view angle changes, the position of the shield needs to be readjusted accordingly. Unfortunately, it may be difficult to use the ceiling-mounted shields effectively in some situations, especially in lateral or oblique projections. The head dose of the second operator can be higher than that of the first one, depending on the configuration of the ceiling-mounted shield and the staff [27]. It is not always easy to use a ceiling-mounted shield effectively, but again, it is worth overcoming the difficulties associated with its use. To overcome difficulties, appropriate knowledge and education are a necessity [26]. Electronic dosimeters are useful for educating the staff. Experiencing a significant dose reduction induced by ceiling-mounted shields monitored with electronic dosimeters will motivate the operators to continue using the shields

[13]. In addition, the development and dissemination of educational materials for the proper use of ceiling-mounted shields is warranted [28].

Protective eyewear

Leaded protective eyewear plays a complementary role to the ceiling-mounted shields in the radiation protection of the lens of the eye. Lead glasses can significantly reduce the radiation dose when protecting against X-rays from the front in the same horizontal plane as the eyes, with a DRF of more than five for glasses with the lead equivalent thickness of more than 0.5 mmPb and a DRF of around 2.5 for glasses with around 0.1 mmPb [29, 30]. However, the effectiveness of dose reduction by protective eyewear is highly dependent on the head's position and angle [31-33]. DRFs of the eyewear for X-rays incident on the front are highly correlated with the lead equivalent thickness, but the correlation worsens as the incident angle increases because the influence of the eyewear design becomes larger [30, 34].

Furthermore, the design of the protective eyewear is so important for dose reduction that glasses with a lead equivalent thickness of 0.07 mmPb may even have a higher dose reduction effect than glasses with a lead equivalent thickness of 0.75 mmPb [35, 36]. The factors of eyewear design that affect dose reduction effectiveness include the sizes and shapes of the glasses and the gaps between the glasses and the face. Side shields or wrap-around shapes increase the coverage of the sides of the face and improve the dose reduction effect from oblique angles [29, 30, 34, 36]. Larger vertical sizes of the glasses can help reduce scatter radiation from the caudal direction [30, 34]. The gap between the glasses and the face is considered as the major source of scattered radiation reaching the eyes and the primary cause of angular dependency of the DRF [32, 37], which will cause significant variability in clinical settings [19]. Every effort to decrease the gap should be made for a consistent reduction of the lens dose in clinical practices. Eyewear modifications that decrease the gap between the glasses and the face can reduce radiation exposure to the eye [38]. To minimize the gap regardless of individual differences in the shape of the head and face, the protective eyewear would need to have some kind of adjustment mechanism [39].

Distance, posture, and configuration

Distance is one of the three principles of radiation safety [40]. The radiation dose is inversely proportional to the square of the distance. Working as far away from the patient as possible can reduce the operators' exposure dose; if the distance from the irradiated area is increased by 40%, the radiation exposure to the operators is reduced by half. The position of the monitor and control panel, the access site such as femoral or radial, and the length of the devices such as catheters and guidewires should be optimized, considering both the ease of the successful procedure and the distance to reduce exposure. Changing to the longer system during the procedure, such as the introduction of a co-axial catheter system, is a good opportunity to decrease the operator's dose by repositioning the display monitor and standing away from the irradiated area.

The height of the head will change the scatter radiation dose and the shielding effect of protective eyewear. The taller the operator, the greater the distance between the patient's irradiated area and the operator's head, so the lens dose of the operator decreases if the protective eyewear is not used. If the head position is quite low, as in a seated operator, the distance between the irradiated area and the head of the operator is close, and so the lens dose will be remarkably high. However, if the operator puts on a protective eyewear, the situation can be altered and even reversed [33]. The taller the height of the operator, the lower the incidence angle of the scatter radiation. Because a lower incidence angle allows more scatter radiation to pass through the gaps between the glasses and the face, the shielding effect of the protective eyewear is lower for taller operators. Therefore, the relationship between the head height and the lens dose depends on the performance of the protective eyewear, i.e., design and lead equivalent thickness.

Furthermore, the posture of the head will affect the shielding performance of the eyewear, or even more [31, 32]. The dose reduction effect of some protective eyewear can dramatically decrease to almost none in a looking-up posture at an angle of only 15°. The looking-up posture results in more scatter radiation passing through the gaps between the glass and the face, so the operator should avoid such a posture. For the same reason, the operators should not lean forward and stick their face above the patient's bed. An appropriate position of the display monitor is the key to preventing looking up or leaning forward. Monitors that are too far or too high will cause inappropriate head postures that may ruin the shielding effect of the protective eyewear.

The configuration of the equipment and instruments also affects the occupational dose to the staff [40]. Exposure from scatter radiation is larger at the side of the X-ray tube than at the side of the image detector [41]. An under-couch system, where the X-ray tube is placed under the table, provides better protection of the head and neck from scattered dose than an over-couch system. For the lateral view, we should stay on the side of the image detector to achieve the benefits of shielding effect of the detector and the patient's body.

Conclusion

The radiation dose of the lenses of the eyes of the medical staff involved in fluoroscopy-guided interventional procedures should be properly monitored. The collar dosimeter is necessary to avoid underestimation of the lens dose, and the dosimeter behind the protective eyewear would be helpful for the staff who are likely to exceed the dose limit. In addition, ceiling-mounted shields are effective if they are properly used, so educational training on the appropriate use is crucial. Minimizing face-to-glass gaps is the key to effective and angle-independent shielding by protective eyewear. Optimization of procedures and devices to keep the distance and avoid the looking-up posture will substantially reduce the lens dose.

Conflict of Interest: None

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