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Challenges in Occupational Dosimetry for Interventional Radiologists

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Abstract This review presents the challenges met by interventional radiologists in occupational dosimetry. The issues mentioned are derived from the recommendations of the International Commission on Radiological Protection, the CIRSE guidelines on "Occupational radiation protection in interventional radiology" and the requirements of the European directive on Basic Safety Standards. The criteria for a proper use of personal dosimeters and the need to introduce optimization actions in some cases are set out in this review. The pros and cons of the electronic real-time dosimeters are outlined and the potential pitfalls associated with the use of personal dosimeters summarized. The electronic dosimeters, together with the appropriate software, allow an active optimization of the interventional procedures.

Keywords Occupational radiation protection · Personal dosimetry · Real-time electronic dosimetry · Interventional radiology

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Introduction and International Recommendations

Interventional radiology (IR) is one of the most evolving medical specialities with one of the highest risks of occupational radiation exposure and therefore represents numerous challenges for personal dosimetry [1, 2]. The International Commission on Radiological Protection (ICRP) published several reports with recommendations to help protect patients and staff against radiation risks during fluoroscopy guided procedures. One of the first reports, published in 2000, referred to the necessity of avoiding radiation injuries in interventional radiology, mainly in patients (skin injuries) but also alerted on radiation-induced cataracts in staff [3]. In that report, ICRP suggested the use of two personal dosimeters for interventionists [3].

In 2010, the Society of Interventional Radiology (SIR) in North America, and the Cardiovascular and Interventional Radiology Society of Europe (CIRSE) published joint guidelines on "Occupational radiation protection in interventional radiology". The guidelines were produced to assist in the reduction in occupational radiation dose [4].

In April 2011, the ICRP approved the "Statement on Tissue Reactions" considering the epidemiological evidence on radiation-induced cataracts with doses lower than the ones previously considered as threshold, and recommending 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 [5]. Compared to the previously existing dose limit of 150 mSv/year, this new limit for the lens of the eyes was a major change that was to be adopted by the European regulations in 2013 [6].

In those years, the European Commission and the International Atomic Energy Agency (IAEA) launched several research programmes to estimate lens doses and radiation-induced cataracts or lens opacities in interventionists, among which are RELID (Retrospective Evaluation of Lens Injuries and Dose, ORAMED (Optimization of RAdiation protection for MEDical staff), ELDO (Eye Lens Dosimetry), EURALOC (EUropean epidemiological study on RAdiation-induced Lens Opacities among interventional Cardiologists), etc. [7–11].

For most of the IR procedures, the approach to use a factor of 0.75 to multiply the dose value measured by the dosimeter over the apron was considered a reasonable approach to estimate the lens dose [2, 12]. Principi et al. evaluated the influence of the external dosimeter position for the assessment of eye lens dose during interventional cardiology [13].

To clarify some of the issues dealing with occupational radiation protection, the ICRP has recently published a new document insisting on several procedural aspects and recommending that occupational protection should be integrated with patient radiation protection [2].

The new generation of active electronic personal dosimeters with its associated software offers the opportunity to manage occupational data for individual IR procedures as well as for different irradiation events that occur during the procedures. An irradiation event is defined in the DICOM documents, as a single use of radiation during a continuous length of time as part of the examination. Active dosimeters also allow suggesting optimization strategies for the operators with dose values higher than the ones considered as “standard values” for specific procedures. The registration in a central database by the associated software of the date, time and the interventional suite [14–17] allows auditing the regular use of the dosimeters.

In this review, we summarize the main issues for a proper use of personal dosimeters in interventional suites and we analyse the pros and cons of the real-time dosimeters with their potential pitfalls. More practical aspects on occupational radiation protection will be included in another paper of this journal.

How to use Personal Dosimeters in Interventional Laboratories?

Any programme on occupational radiation protection for IR should consider adequate protection and dose monitoring for the staff. The ICRP and the CIRSE guidelines [2, 4] recommend using two personal dosimeters. This approach allows, in addition to estimate lens doses, to combine the readings of the two dosimeters in order to calculate a more reliable estimate of effective dose [2, 18]. During some specific procedures, when the hands of the operator happen to be near the radiation field, using a third (finger) dosimeter could be justified. The medical physics expert or the radiation protection expert should advise and audit the personal dose monitoring to recommend improvements in the occupational radiation safety [2, 4, 19].

Not all the professionals working in an interventional laboratory may need the same level of monitoring. The main factors to be considered are the work to be done, the distance from the patient, the workload and the complexity of the procedures. The level of exposure may be different for the operators, nurses, radiographers, anaesthetists, ultrasonographers, etc.

ICRP recommends ambient monitors (e.g. on the C-arm, fig. 1) to assess scatter radiation fields continually, to provide backup to personal dosimetry, to discover noncompliance in wearing individual dosimeters and to help estimate occupational doses when personal dosimeters have not been worn [2, 20]. The evaluation of the radiation risks may sometimes require a personal dosimetry evaluation (during a limited period of time) to decide if a second dosimeter is justified.

It should be noted that the primary goal of the personal dose monitoring is to confirm that the personnel works properly protected and is exposed to occupational doses below the regulatory limit. In many European countries, the regulatory authority periodically audits the occupational doses. Nevertheless, it is in general possible neither to audit radiation protection during clinical practices nor to confirm that personal dosimeters are regularly worn during all the interventional procedures. Working below the limits is not a guarantee of a good radiation protection. The optimization principle should also be applied. Occupational doses should be as low as reasonably achievable (ALARA) but also compatible with the clinical outcome of the procedures. A dialogue between clinicians and medical physicists (where and if available) is required to analyse the optimization strategies.

Personal dosimetry is one of the most challenging issues in the protection of interventional radiologists and the staff, as the level of radiation they may be exposed to can be exceedingly high. In case of an erratic use of the personal dosimeters, improving personal protection will prove impossible and the result after several years of work may be the increase in the probability of malignancies and opacities (or cataracts) in the lens of the eyes [2, 7, 8]. The evaluation of the radiation dose to the lens of the eyes is relevant to advice on the potential need of ocular radiation protection [19].

Interventionists should know the level of radiation exposure they might receive while working with different imaging modes (fluoroscopy, cine, digital subtraction angiography -DSA, cone beam computed tomography - CBCT, CT fluoroscopy in CT Guided interventions, etc.), different C-arm angulations, the geometry of the X-rays system and CT gantry, the patient size, etc. All these

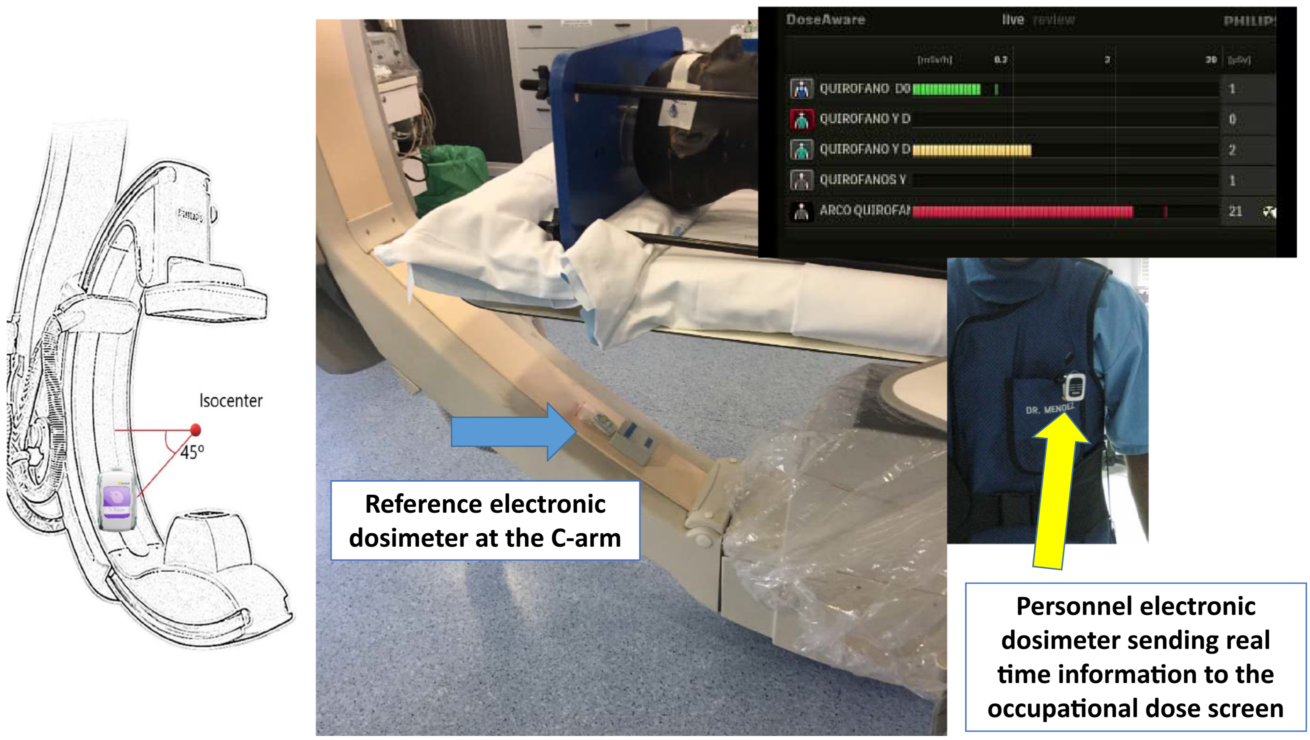

Fig. 1. Typical position of the C-arm reference dosimeter and personal active dosimeter (over the protective apron). Display with occupational dose rates inside the catheterization room with logarithmic scale. Green indicates low scatter dose rates, yellow for medium scatter rates and red the highest scatter dose rate (in this case, the red corresponds to the C-arm reference dosimeter).

aspects should be an inherent part of the radiation protection training programme [20]. European regulations require this training [6]. ICRP proposed a second level of training (and certification) in radiation protection for interventionists, in addition to the training recommended for other physicians who use X-rays [20].

Active electronic Dosimeters

The new generation of electronic dosimeters uses silicon diode detectors, specially designed to measure "personal dose equivalent" and to provide cumulative doses and dose rates. Their detection threshold is usually in the range of a few µSv and tenths of µSv/h. They can measure up to several hundreds of mSv/h [21].

These dosimeters with the associated software allow managing information on the occupational doses for each procedure and in some cases for each radiation event (fluoroscopy and image acquisition runs). Part of this information may be shown inside the catheterization room. Occupational doses may be linked with patient dose values and with the technical and geometry parameters of the X-ray systems and the date and time of the procedure and the interventional laboratory [22, 23]. An additional reference dosimeter (ambient dosimeter) at the C-arm (Fig. 1) could also be used to detect the proper use of the ceiling suspended screen during the procedure [14, 21]. The ratio between the occupational doses received by the personal electronic dosimeters held over the lead apron and the dose measured by the reference dosimeter at the C-arm can be automatically calculated individually for each procedure from the collected data by the associated software. If the ceiling suspended screen is in the proper position, the reference C-arm detector (not shielded) should receive much more radiation than the dosimeters of the operators. This ratio between the values of the two dosimeters may be used as an alert to improve the use of the ceiling suspended screen.

In the near future, the advances in artificial intelligence will also contribute to estimate the range of occupational doses with video cameras and the appropriate software to follow the position of the operator, the geometry and the technical parameters of the X-ray system in accordance with the type of the procedure [2].

Pros and Cons of Real-time Dosimeters

The "pros":

1 Monitor and send wirelessly to the database, the occupational doses per procedure and, in some cases, for different irradiation events (fluoroscopy, cine, DSA or CBCT runs). Occupational doses and dose rate

values may be displayed inside the interventional room. This information may also be relevant for the analysis of unintended or accidental exposures [24].

2 Allow comparing these dose values with a reference ambient dosimeter at the C-arm to verify the proper use of the ceiling suspended screen [21].

3 Allow auditing the proper use of personal dosimeters if a central database exists with the procedures carried out by different interventionists, with the registry of date, time and interventional room.

4 Enhances an active optimization when one monitor located in front of operators, inside the interventional laboratory, displays in real-time the occupational dose rate during each and every procedure (see Fig. 1).

5 Occupational doses per procedure may also be compared with the results of other interventionists (anonymizing the data of the occupational doses) working in the same interventional room and performing procedures of similar complexity.

6 Allow the estimation of lens doses for each interventional procedure from the dosimeter worn above the apron and identify the riskiest procedures and C-arm angulations.

The “cons”:

1 Many regulatory authorities have still not approved these dosimeters as legal systems for occupational dosimetry. As a consequence, the passive conventional dosimetry systems should be used in parallel (with associated inconvenience and extra costs).

2 Additional expenses in investing in a set of electronic wireless dosimeters, X-ray “hubs” to collect the data from the occupational dosimeters in the interventional rooms, and the associated software.

3 Electronic active dosimetry may be limited due to a certain lag of some seconds, between radiation exposure and display of the real time dosimeters.

4 Need of medical physics experts who are skilled in managing the data and suggesting optimisation actions.

Potential Pitfalls in Using Personal Dosimeters and Reporting Occupational Dose Values

- The irregular use or even the lack of use of the dosimeters. Some interventionists often choose not to wear their dosimeters, in order to avoid investigations of the regulators [18].
- The dosimeter may be stored in a location where it is exposed to unintended radiation.
- When the interventionist uses two dosimeters (over and under the protective apron) an error in the position may occur (over-under apron).
- Errors reporting occupational doses from IR practices to international and national databases. A problem at large hospitals derives from the difficulty to identify the different professional groups involved in interventional practices [25].

Conclusions

Personal dosimeters should be used, one under the protective apron and the other one above the apron. This second dosimeter allows a rough estimation of the dose to the lens of the eyes. The proper use of personal dosimeters should be part of the radiation protection training and included in the audit programmes.

Active occupational dosimetry in interventional radiology can be used not only to audit if interventionists comply with the regulatory dose limits but also to optimize occupational protection for each procedure.

Electronic active wireless dosimeters, together with the appropriate software, allow gathering information on occupational doses and dose rates in real time during (or immediately after) the procedures. Occupational doses per procedure should be compared with standards of good practice.

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Compliance with Ethical Standards

Conflict of interest All the authors declare that they have no conflict of interest.

Consent for Publication For this type of paper, consent for publication is not required. All the authors have approved the submitted manuscript.

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