Received: 2 November 2020 | Revised: 26 July 2021 | Accepted: 28 July 2021

DOI: 10.1002/mp.15148

MEDICAL PHYSICS

TECHNICAL NOTE

# Managing occupational doses with smartphones in interventional radiology

**Roberto M. Sánchez**[1,2,3] | **Daniel Fernández**[4] | **Eliseo Vañó**[2,3] | **José M. Fernández**[1,2]

[1]Medical Physics, Hospital Clínico San Carlos, Madrid, Spain

[2]Instituto de Investigación Sanitaria del Hospital Clínico San Carlos, Madrid, Spain

[3]Medicine Faculty, Universidad Complutense de Madrid, Madrid, Spain

[4]Software Engineering, Universidad Francisco de Vitoria, Madrid, Spain

**Correspondence**
Roberto M. Sánchez, Servicio de Física Médica, Hospital Clínico San Carlos, Profesor Martín Lagos sn, 28040 Madrid, Spain.
Email: robertomariano.sanchez@salud.madrid.org

**Funding information**
Carlos III Health Institute; European Regional Development Fund; Spanish National Safety Council

## Abstract

**Purpose:** This study presents a prototype smartphone application for occupational dosimetry in interventional practices based on electronic personal dosimeters to assist in dose monitoring.

**Methods:** The prototype receives and records information from the occupational dose report containing the cumulative dose of electronic personal dosimeters worn over the apron at chest level and electronic area dosimeters located on C-arms (reference dosimeters), for each fluoroscopy-guided procedure. Using their smartphones, personnel involved in interventional practices can review and compare their occupational records with an investigation level, the dose limits, and their department colleagues (anonymously). The ratio between $H_p(10)$ measured by the personal and the reference dosimeters at the C-arm is presented as an indicator of consistent use of suspended operator shield. Some general results extracted from the first months of use are presented.

**Results:** The reference dosimeter located at the C-arm (without lead protection and acting as an ambient dosimeter) recorded in one of the laboratories 217 mSv during 308 procedures over 5 months, showing an indication of the radiation risk present in an interventional laboratory. The ratio between the personal cumulative dose and the dose at a reference C-arm dosimeter ranged from 0.2% to 1.67% (a factor of 8.5) for different interventionalists. These differences suggest different protection habits among interventional operators, as well as a target for dose reduction.

**Conclusions:** With this system, professionals have easy access to their occupational dosimetry records (including information on the workload) in the setting of their interventional departments, to thereby actively engage in the protection process.

**KEYWORDS**
active dosimeters, interventional procedures, occupational dose, radiation protection

## 1 | INTRODUCTION

For professional activities that involve the use of ionizing radiation, fluoroscopy-guided interventions carry the highest occupational radiation risk. Several cases of radiation-induced lens opacity and cataracts have been reported among interventional practitioners,[1-5] suggesting that interventional practices increase the risk of cataracts.[6] The International Commission on Radiological Protection has published recommendations for fluoroscopy-guided procedures to prevent patient and professional radiation injuries,[7-9] and a number of these recommendations have been adopted by European regulations, establishing new occupational dose limits and the requirement for optimizing procedures to keep occupational doses as low as possible.[10]

A number of international programs have promoted actions to assess lens doses during medical procedures. The Retrospective Evaluation of Lens Injuries and Dose (promoted by the International Atomic Energy Agency*), the Optimization of Radiation Protection for Medical Staff†, Eye Lens Dosimetry, and the European Epidemiological Study on Radiation-induced Lens Opacities among Interventional Cardiologists (EURALOC‡) projects have stressed the radiation risks for interventionalists and have proposed radiation protection guidelines and improvements in radiation monitoring of eye lenses.

Occupational dose records are essential for ensuring adequate protection for exposed workers, although obtaining realistic occupational dose values for interventionalists remains a challenge. The International Commission on Radiological Protection stated, "Reported occupational dose values are often surprisingly low, and the reason is not likely to be a high level of radiological protection but rather failure to wear personal dosimeters. Failure to wear dosimeters is a problem throughout the world".[9] Any proposal for improving occupational dose records would therefore be welcome. Facilitating interventionalists' quick and easy access to dose record information could result in a greater interest in the correct use of occupational dosimeters. EURALOC developed the mEyeDose utility that shows the occupational eye lens dose estimated using EURALOC methodology.[11,12] There is a commercial product that combines occupational electronic dosimeters with applications showing the occupational dose rate in real time.[13] More recently, utilities have been developed that can combine the occupational dose records with the patient radiation dose structured report into what can be termed an occupational dose report (ODR).[14,15] This technology makes it possible to record the patient and occupational dose per procedure and per radiation event, thereby making it possible to record information on the occupational radiation dose with other measurements related to the workload and to analyze whether the high doses are caused by a high workload/complexity or inadequate protection.

In this study, we present a prototype that, by taking advantage of electronic personal dosimeters and ODRs, can display the measured occupational dose to interventional operators (or other professionals involved in the procedures or their radiological protection) on their smartphones or personal computers, including information on the workload (number of procedures, fluoroscopy, digital acquisition, and total radiation times). Interventionalists can also compare their records with their department colleagues, thereby encouraging the interventionalists to take a more active role in obtaining high-quality dosimetry records and to lower occupational dose. These dosimeters are in addition to the official passive dosimetry required by the authority; in this center, interventionalists wear two thermoluminescent dosimeters at chest level, one under and the other over the protection apron.

## 2 | MATERIALS AND METHODS

The interventional cardiology and interventional radiology departments from a university hospital participated in this pilot program. Both departments include seven interventional laboratories with an activity of more than 5000 interventional procedures per year. Electronic personal dosimeters model i3 (RaySafe) were offered to interventionalists to be worn over the apron at chest level (in addition to official passive dosimetry). A total of 10 out of 15 interventionalist accepted voluntarily to use the dosimeter in a personal (and non-transferable) way. The occupational dose measured over the apron at chest level may be used as a rough estimate of the eye lens dose if no additional protection devices (such as goggles) are employed.[16-18] These dosimeters are typically used together with an in-lab display to show the occupational dose rate in real time, but they are also capable to record the occupational dose rate and cumulative dose every second. A reference dosimeter (also RaySafe i3) was located on each C-arm to measure the level of scatter radiation produced in the interventional rooms. This reference dosimeter is attached to the lower part of the C-arm (drawing a 45° line with the C-arm rotation axis) as shown in Figure 1, which is one of the points with the highest scatter radiation resulting from patient backscatter. Well-protected operators should receive much lower doses than these reference dosimeters.

The employed dosimeter, the model i3 was designed to measure occupational radiation doses ($H_p(10)$) during

*https://www.iaea.org/resources/rpop/resources/relid-study

†https://www.oramed-fp7.eu

‡https://www.euraloc.eu/en/About_Euraloc

interventional procedures. For this model, the manufacturer declared an energy dependence of less than 25% (N40-N150 ISO narrow beam series), a detection limit of 30 μSv/h, an integration time of 1 s, a dose rate uncertainty of 10% for dose rates between 40 μSv/h and 150 mSv/h and 20% for dose rates between 150 and 300 mSv/h. The manufacturer also warned that the dosimeters might have a temperature dependence of 5% between 15 and 26°C but that this dependence could reach 20% for temperatures over 26°C. To assure an acceptable response to the typical pulsed radiation beams present in interventional practices, the Medical Physics Service has tested the dosimeters versus a reference dosimeter calibrated in a secondary laboratory (EPD Mk2; Thermo Scientific). The EPD Mk2 and test dosimeters were exposed simultaneously to the scatter pulsed radiation beams from an interventional X-ray system of different beam qualities (60, 80, and 100 kV with 1.8 mm Al of added filtration). Test dosimeters readings were compared to reference reading. The mean difference for all exposures resulted in −3% with a standard deviation of 8% and with a maximum difference of −33%. No correction was applied to dosimeters readings, but the dosimeter with the highest difference was retired from use. The RaySafe i3 electronic dosimeters can communicate wirelessly with hubs installed at each interventional laboratory that record the occupational dose measurements and dose rates every second. These hubs synchronize the occupational dose records with the information from the Digital Imaging and Communications in Medicine (DICOM) radiation dose structured report to create an ODR. The ODR is a nonstandardized structured report built with a structure similar to the standardized radiation dose structured report, that includes the information on an occupational dose at the irradiation event level. The hubs can send the ODR to a destination when the procedure is closed in the X-ray system. All of these elements form part of the DoseWise system (Philips Healthcare).

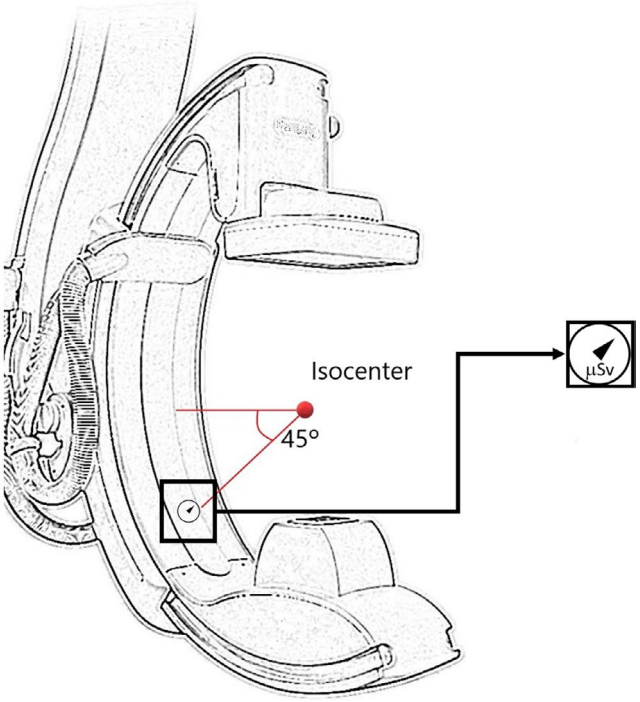


**FIGURE 1** Location of the C-arm dosimeter

Using these hubs and electronic dosimeters, we constructed another processing station consisting of a DICOM listener (using the open source, cross-platform, interface engine Mirth) to receive the ODR sent by the hub, a recorder to extract the key information at the procedural level for storage in a database (MySQL server), and a web application to show the most relevant pieces of information to all personnel involved in interventional

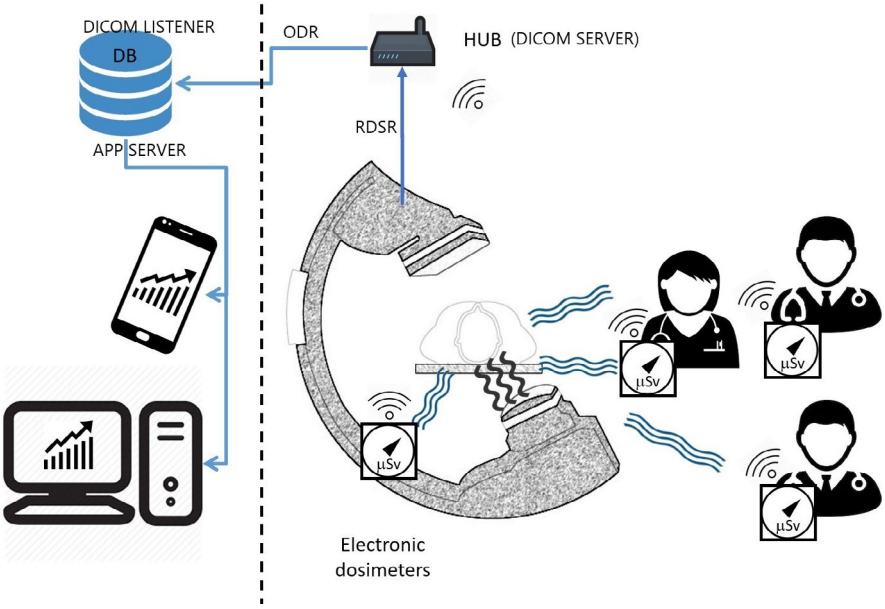


**FIGURE 2** Diagram describing the system. Electronic dosimeters measure cumulative dose and dose rate each second sending to the HUB wireless. The HUB creates an occupational dose report using de dosimeter information and the modality information on radiation events and study unique identifiers. A Digital Imaging and Communications in Medicine (DICOM) listener receives the occupational dose report (ODR) and stores the dosimetric information to be shown on smartphones or PCs

procedures (Figure 2). Thus, once the procedure is finished and closed in the interventional unit and the DICOM messages are delivered to the servers, the information is processed and available for consultation within 1 or 2 min. No additional correction was performed on the readings from the personal dosimeter (placed on the apron at chest level) to estimate other occupational radiation protection quantities such as effective dose and eye lens dose.

## 2.1 | Information displayed to interventional workers on their smartphones

Using our dosimeter application, users of electronic personal dosimeters can see (either on a personal computer or smartphone) a screen similar to that shown in Figure 3, which displays (in a customizable period from 1 day to several months) the cumulative occupational dose, the cumulative radiation time and information regarding the legal dose limits and investigation levels. A "traffic light" beside the cumulative occupational dose value indicates whether the investigation level for the selected period of time (amber) or the dose limit (red) has been exceeded. The investigation level was set to 6.7 mSv/year, a cumulative dose that if exceeded should prompt an improvement in occupational radiation protection. The dose limit was set to 20 mSv/year. An average of the cumulative dose of the users' professional profile for the time period selected is shown as "professional profile average" (nurse, interventionist, etc.). If high deviations are found, he or she can consult with the radiation protection specialist to seek for the causes of such deviations like workload, complexity, or bad protection. Information regarding the workload is shown as the number of procedures and radiation time (for fluoroscopy and cine or other digital imaging acquisition mode). The average value of the ratio of the personal dosimeter's cumulative dose over the reference dosimeter (located at the C-arm) is also shown as "% Reference". This quantity is calculated and recorded for each interventional procedure and for every personal dosimeter present in the room, and the app shows the mean value for the user's dosimeter over the selected period of time (also with a colored circle), indicating whether it is under 2% (green), over 2% (amber), or over 5% (red). This quantity can be used as an indicator of protection for optimization purposes

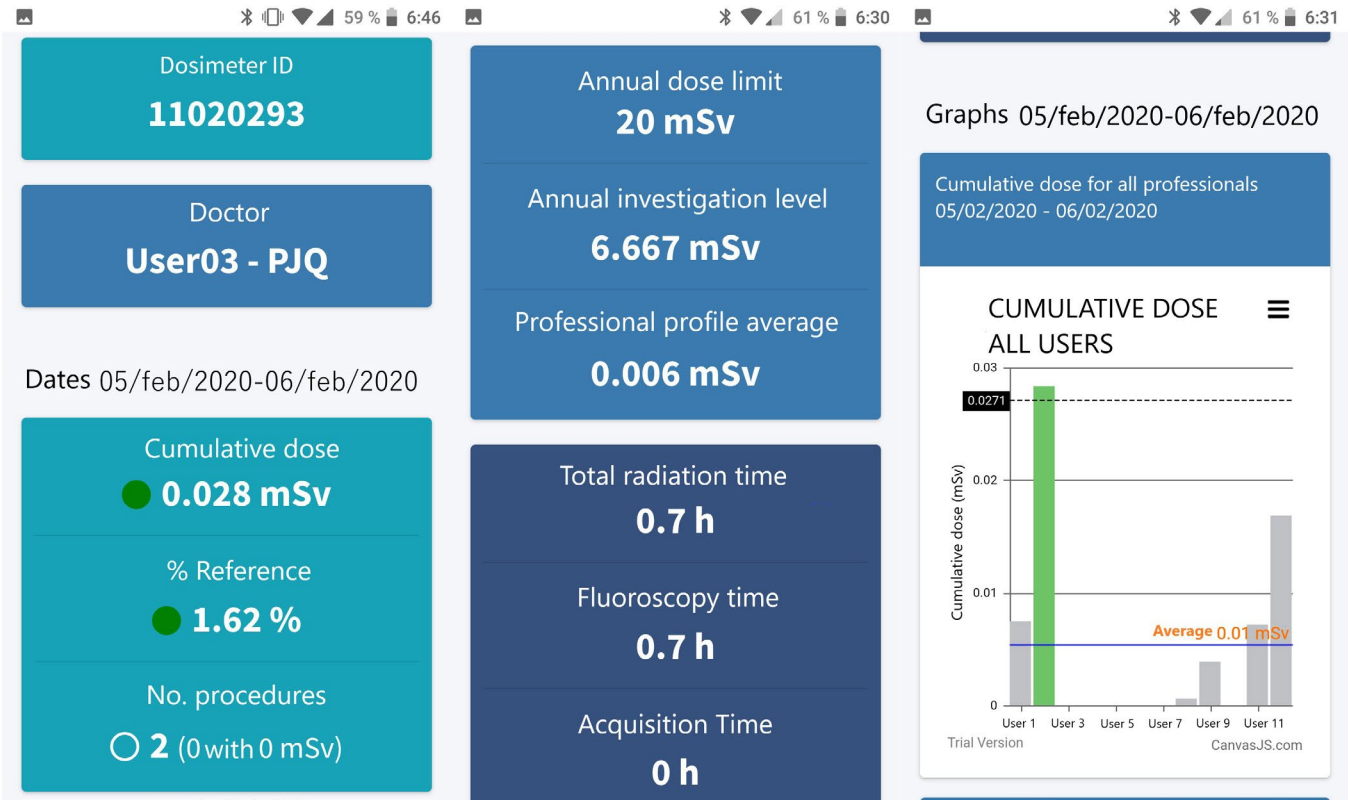


**FIGURE 3** Left to right: Screenshots of the user interface from a smartphone showing the records for 1 day. Left: Identification, the cumulative dose, the % reference, and the number of procedures. The green traffic light indicates good compliance with the center's radiation protection policy. Center: Information about dose limits, quantities to compare with, and radiation time. Right: cumulative doses for all users. The green bar indicates the logged-in user

**TABLE 1** Main radiation parameters for operators from January to May/2020. Total radiation time includes fluoroscopy and digital acquisition (cine or DSA)

| Operator | Cumulative $H_p(10)$ over the apron (mSv) | % of reference dosimeter | No. of procedures | Total radiation time, h | Fluoroscopy time, h |
|---|---|---|---|---|---|
| 1 | 1.2 | 1.30 | 129 | 37.9 | 35 |
| 2 | 1.8 | 1.67 | 165 | 54.1 | 50.8 |
| 3 | 0.2 | 0.20 | 143 | 51.7 | 49.1 |
| 4 | 0.8 | 1.05 | 107 | 29.2 | 26.7 |
| 5 | 1.0 | 1.03 | 145 | 38 | 35.1 |
| 6 | 0.1 | 0.20 | 57 | 18.1 | 16.7 |
| 7 | 0.7 | 1.07 | 82 | 18.9 | 17.2 |
| 8 | 1.4 | 1.36 | 169 | 52 | 46.6 |
| 9 | 1.8 | 1.27 | 139 | 45.7 | 41.1 |
| 10 | 1.3 | 1.30 | 134 | 45.7 | 41.1 |

Abbreviation: DSA, digital subtraction angiography.

**TABLE 2** Main radiation parameters recorded at the C-arm from January to May/2020

| | Department | Cumulative $H_p(10)$ at C-arm (mSv) | No. procedures | Tot. radiation time (h) | Fluoroscopy time (h) |
|---|---|---|---|---|---|
| Room 2 | Interventional cardiology | 206 | 229 | 57 | 52 |
| Room 3 | Interventional cardiology | 217 | 308 | 72 | 66 |
| Room 4 | Interventional cardiology | 60 | 92 | 37 | 35 |
| Room 5 | Interventional cardiology | 48 | 147 | 27 | 25 |
| Room 6 | Interventional radiology | 177 | 301 | 44 | 41 |
| Room 7 | Interventional neuroradiology | 128 | 154 | 44 | 40 |

and the rationale of the choice of these ranges is explained by Vano et al.[19] The occupational dose can be compared with those of all other department workers (or compared with workers of the same profile, such as doctors and nurses) (Figure 3, right).

Administrators (radiation protection or medical physics experts) can also see the information relative to the reference dosimeters (located on the C-arm) and all information relative to the dosimeter users. Along with the number of procedures, the application indicates how many of the procedures have been recorded in the database with a cumulative dose of 0 mSv. If the procedure is too short or the practitioners have been very well protected with the suspended operator shield or have participated as a second operator, the resulting cumulative dose might be very low and present as 0 μSv. However, if the number of procedures with 0 mSv is too high, the application might alert the user about incorrect use of the dosimeter. If the dosimeter is stored near the hub, the hub will detect and record this dosimeter as participating in the procedure, producing an overestimate of the workload for its user. If the administrator of the system detects an unusually high value for this parameter (procedures with 0 mSv), they can investigate the cause and correct it if necessary.

All interventionalists in this center have been trained in radiological protection as required by national and European regulations.

## 3 | RESULTS AND DISCUSSION

Table 1 lists the main parameters shown by the application for a period from January 14 to May 18, 2020. The total radiation time includes fluoroscopy and other digital imaging acquisition systems (such as cine, digital subtraction angiography [DSA], and cone-beam computed tomography).

For the practitioners included in the survey, the maximum cumulative dose over the apron for the 4 months was 1.8 mSv (Table 1). If this trend is confirmed, the cumulative dose will then be kept under the regulatory limits for the eye lens (20 mSv/year averaged over 5 years, with no single year exceeding 50 mSv, as recommended by ICRP[20]). The highest ratio for the personal dosimeter value to reference dosimeter value was 1.67%, indicating that all practitioners were well protected using the ceiling-suspended screen and/or by acquiring the DSA series behind a shield or by moving to the control room.[19] It is possible, however, to see an 8.5-factor difference in the reference dosimeter

percentage between the minimum 0.20% and the maximum 1.67%, which might indicate that the use of the ceiling-suspended screen could be improved for certain operators. Using the data from Table 1, when the correlation was analyzed between occupational dose and radiation time, acquisition time ($r^2$ = 0.55) resulted in higher correlation than fluoroscopy time ($r^2$ = 0.3) or total radiation time ($r^2$ = 0.34). These results could be different for different professionals or specialties if, for example, the interventionalists uses automatic contrast injectors and acquire DSA from the control room.

Dose values from reference dosimeters on the C-arms for January to May/2020 period are shown in Table 2. The highest record for the cumulative dose in the reference dosimeter at the C-arm was 217 mSv, with 72 h of radiation (fluoroscopy and digital acquisition) over 308 procedures in one interventional cardiology C-arm (from four catheterization labs fully dedicated to cardiac procedures). This remarkable cumulative dose provides an idea of the amount of radiation that can be measured in these types of rooms.

## 4 | CONCLUSIONS

We present a prototype system for the management of occupational dosimetry in interventional practice based on the electronic personal dosimeters combined with information on the workload. With this prototype, interventionalists and other practitioners involved in interventional practices can (using their smartphones or personal computers) check their measured occupational doses and compare them with an investigation level, the legal dose limit, a reference dosimeter at the C-arm, and their department colleagues. This application makes available the dosimetry information of these electronic personal dosimeters in the smartphone (or PC) with immediate access, either after performing a procedure or to see temporal trends. This allows interventionists to be involved in a more active improvement of radiation protection during their clinical work. Along with appropriate training in radiological protection, the better access to the occupational dose information achieved with this tool can improve the operator engagement with radiation protection principles and better compliance in wearing dosimeters, helping to optimize interventional practices and occupational safety. Next steps in the project include the comparison between different specialties like interventional radiology and cardiology.

## ACKNOWLEDGMENTS

The authors would like to thank the Spanish Economy and Competitiveness Fund (Carlos III Health Institute) and the European Regional Development Fund (ERDF) under the project MEDICI number PI16/01413 and the Spanish National Safety Council under the project EDOCI.

## CONFLICT OF INTEREST

There are no actual or potential conflicts of interest to declare in relation to this paper.

## DATA AVAILABILITY STATEMENT

Data are subject to third-party restrictions. Data presented are personal occupational records subject to the Spanish and European regulations for personal data protection.

## REFERENCES

1. Vano E, Gonzalez L, Fernández JM, Haskal ZJ. Eye lens exposure to radiation in interventional suites: caution is warranted. *Radiology*. 2008;248(3):945-953. doi:https://doi.org/10.1148/radiol.2482071800
2. Vañó E, González L, Beneytez F, Moreno F. Lens injuries induced by occupational exposure in non-optimized interventional radiology laboratories. *BJR*. 1998;71(847):728-733. doi:https://doi.org/10.1259/bjr.71.847.9771383
3. Vano E, Kleiman NJ, Duran A, Romano-Miller M, Rehani MM. Radiation-associated lens opacities in catheterization personnel: results of a survey and direct assessments. *J Vasc Interv Radiol*. 2013;24(2):197-204. doi:https://doi.org/10.1016/j.jvir.2012.10.016
4. Ciraj-Bjelac O, Rehani MM, Sim KH, Liew HB, Vano E, Kleiman NJ. Risk for radiation-induced cataract for staff in interventional cardiology: is there reason for concern? *Cathet Cardiovasc Intervent*. 2010;76(6):826-834. doi:https://doi.org/10.1002/ccd.22670
5. Jacob S, Boveda S, Bar O, et al. Interventional cardiologists and risk of radiation-induced cataract: results of a French multicenter observational study. *Int J Cardiol*. 2013;167(5):1843-1847. doi:https://doi.org/10.1016/j.ijcard.2012.04.124
6. Seals KF, Lee EW, Cagnon CH, Al-Hakim RA, Kee ST. Radiation-induced cataractogenesis: a critical literature review for the interventional radiologist. *Cardiovasc Intervent Radiol*. 2016;39(2):151-160. doi:https://doi.org/10.1007/s00270-015-1207-z
7. Valentin J, ed. *Avoidance of Radiation Injuries from Medical Interventional Procedures*. ICRP Publication 85. Ann. ICRP 30 (2). Pergamon Press; 2000.
8. Rehani MM, Ciraj-Bjelac O, Vañó E, et al. Radiological protection in fluoroscopically guided procedures performed outside the imaging department. Clement CH, ed. *Ann ICRP*. 2010;40(6):1-102. doi:https://doi.org/10.1016/j.icrp.2012.03.001
9. Cousins C, International Commission on Radiological Protection, eds. *Radiological Protection in Cardiology*. ICRP Publication 120. Ann. ICRP 42(1). Elsevier; 2013.
10. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. Accessed August 11, 2021. https://eur-lex.europa.eu/eli/dir/2013/59/oj
11. Struelens L, Dabin J, Carinou E, et al. Radiation-induced lens opacities among interventional cardiologists: retrospective assessment of cumulative eye lens doses. *Radiat Res*. 2018;189(4):399-408. doi:https://doi.org/10.1667/RR14970.1
12. Covens P, Dabin J, De Troyer O, Dragusin O, Maushagen J, Struelens L. Track, calculate and optimise eye lens doses of interventional cardiologists using mEyeDose and mEyeDose_X. *J Radiol Prot*. 2018;38(2):678-687. doi:https://doi.org/10.1088/1361-6498/aab2e4
13. Sanchez R, Vano E, Fernandez JM, Gallego JJ. Staff radiation doses in a real-time display inside the angiography room.

*Cardiovasc Intervent Radiol*. 2010;33(6):1210-1214. doi:https://doi.org/10.1007/s00270-010-9945-4
14. Vano E, Sanchez RM, Fernandez JM. Strategies to optimise occupational radiation protection in interventional cardiology using simultaneous registration of patient and staff doses. *J Radiol Prot*. 2018;38(3):1077-1088. doi:https://doi.org/10.1088/1361-6498/aad429
15. Sailer AM, Paulis L, Vergoossen L, et al. Real-time patient and staff radiation dose monitoring in IR practice. *Cardiovasc Intervent Radiol*. 2017;40(3):421-429. doi:https://doi.org/10.1007/s00270-016-1526-8
16. Martin CJ. Eye lens dosimetry for fluoroscopically guided clinical procedures: practical approaches to protection and dose monitoring. *Radiat Prot Dosimetry*. 2016;169(1-4):286-291. doi:https://doi.org/10.1093/rpd/ncv431
17. Principi S, Ginjaume M, Duch MA, Sanchez RM, Fernandez JM, Vano E. Influence of dosemeter position for the assessment of eye lens dose during interventional cardiology. *Radiat Prot Dosimetry*. 2015;164(1-2):79-83. doi:https://doi.org/10.1093/rpd/ncu359
18. Farah J, Struelens L, Dabin J, et al. A correlation study of eye lens dose and personal dose equivalent for interventional cardiologists. *Radiat Prot Dosimetry*. 2013;157(4):561-569. doi:https://doi.org/10.1093/rpd/nct180
19. Vano E, Sanchez RM, Fernández JM. Helping to know if you are properly protected while working in interventional cardiology. *J Radiol Prot*. 2020;40(4):1273-1285. https://doi.org/10.1088/1361-6498/abc325
20. Valentin J. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4). 2007

**How to cite this article:** Sánchez RM, Fernández D, Vañó E, Fernández JM. Managing occupational doses with smartphones in interventional radiology. *Med Phys*. 2021;48:5830–5836. https://doi.org/10.1002/mp.15148