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FULL PAPER

Occupational and patient doses for interventional radiology integrated into a dose management system

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Objectives: The International Commission on Radiological Protection recommends managing patient and occupational doses as an integrated approach, for the optimisation of interventional procedures. The conventional passive personal dosimeters only allow one to know the accumulated occupational doses during a certain period of time. This information is not enough to identify if there is a lack of occupational radiation protection during some procedures. This paper describes the use of a dose management system (DMS) allowing patient and occupational doses for individual procedures to be audited.
Methods: The DMS manages patient and occupational doses measured by electronic personal dosimeters. One dosemeter located at the C-arm is used as a reference for scatter radiation. Data have been collected from five interventional rooms. Dosimetry data can be managed for the whole procedure and the different radiation events. Optimisation is done through auditing different sets of parameters for individual procedures: patient dose indicators, occupational dose values, the ratio between occupational doses, and the doses measured by the reference dosemeter at the C-arm, and the ratio between occupational and patient dose values.
Results: The managed data correspond to the year 2021, with around 4500 procedures, and 8000 records on occupational exposures. Patient and staff dose data (for 11 cardiologists, 7 radiologists and 8 nurses) were available for 3043 procedures. The DMS allows alerts for patient dose indicators and occupational exposures to be set.
Conclusions: The main advantage of this integrated approach is the capacity to improve radiation safety for patients and workers together, auditing alerts for individual procedures.
Advances in knowledge: The management of patient and occupational doses together (measured with electronic personal dosimeters) for individual interventional procedures, using dose management systems, allows alerting optimisation on high-dose values for patients and staff.

INTRODUCTION

The International Commission on Radiological Protection (ICRP) recommended managing patient and occupational doses as an integrated approach for the optimisation of fluoroscopy-guided interventional procedures (FGIP).[1] In the same report, ICRP recommended the use of two personal dosimeters for the assessment of occupational exposure. The combination of the readings of two dosimeters, one shielded by the apron and one unshielded above the apron, provides the best available estimate of the effective dose and also provides a reasonable estimation of the equivalent dose to the lens of the eye and the head.[1]

Radiation safety in interventional procedures is still a challenge in many interventional laboratories. Several studies have been published on the prevalence of eye lens opacities in interventionists due to the lack of appropriate radiation protection.[2–6]

The conventional passive personal dosimeters for professionals working in interventional laboratories, only allow one to know the accumulated occupational doses during a certain period of time (usually one month). But this information is not enough to identify if there is a lack of occupational radiation protection during some specific FGIP (*e.g.*, information on the proper use of the suspended ceiling, or equivalent, protective screen). Sailer et al published results demonstrating that the feedback of personal occupational doses increases radiation awareness and ultimately will lead to the optimised behaviour of interventionists.[7]

The automatic registration and simultaneous management of patient dose indicators and occupational doses represent an advantage in radiation safety for interventional radiology, allowing alerts on the lack of proper radiation protection and suggesting optimisation actions.

Most of the available Dose Management Systems (DMSs) are able to manage information for the optimisation of patient radiation protection, but the simultaneous management of occupational doses in the DMS is still scarce.[7–9] The X-ray systems send dosimetric, geometric and other technical details contained in the Digital Imaging and Communication In Medicine (DICOM) Radiation Dose Structured Reports (RDSRs) of interventional procedures, to the Picture Archiving and Communication System (PACS) and also directly, to the DMSs. As part of the quality assurance and radiation safety programmes, a periodic analysis of patient dose values for Air Kerma Area Product (P_{KA}) and Air Kerma at the patient entrance reference point ($K_{a,r}$) is used to verify if the median values of the dosimetric indicators (for a group of procedures with the same clinical indications) are below the local or national Diagnostic Reference Levels (DRLs). For individual procedures, the interest is to detect whether some of them approach the "trigger levels" to consider the clinical follow-up for potential radiation injuries and optimisation.[10,11]

The ICRP recommends using the automated reporting of radiation-dose-related quantities, and also, when available, the radiation events information using the DICOM RDSR.[12,13] In the last years, several approaches have been developed[8,9,14,15] to produce similar reports for occupational doses using electronic active personal dosimeters, which would send the information on dose values wirelessly to "hubs" installed in the catheterisation rooms and, from there, send the "Occupational Dose Reports" (similar to the RDSR for patients) in real-time, to the DMS.

The European Directive 2013/59/Euratom[16] also requires occupational doses in medical exposures for justification (in art. 19.4) and optimisation (in art. 32, b) to be considered. Thus, auditing the radiation protection aspects in medical imaging should include both patient and occupational doses.

This paper follows the recommendations of the ICRP to manage patient and occupational doses as an integrated approach for optimising interventional procedures, discussing the limitations of passive personal dosimeters, and describes the use of active electronic personal dosimeters sending the information on occupational doses to a DMS in real-time, allowing patient and occupational doses for individual procedures to be audited.

METHODS AND MATERIALS

A homemade DMS called DOLQA (Dose On-Line for Quality Assurance), which was designed and improved upon during several years in a large university hospital,[17–19] has been recently updated to also receive and manage occupational doses measured by active electronic dosimeters worn over the protective apron by interventionists (and nurses, in the cardiac rooms).[20]

Data from the full year 2021, for five interventional rooms (all equipped with Philips Allura X-ray systems) have been processed. Three for interventional cardiology, one for general interventional radiology (called "vascular" room) and another (biplane system) for interventional neuroradiology.

The personal dosimeters used are the model "i3 RaySafe" (Unfors RaySafe AB, Billdal, Sweden), which were offered to interventionists to be worn over the apron, at chest level, in addition to official passive dosimeters (worn under the lead apron) required by the national regulatory authority.

We use the term "occupational dose" when referring to the "personal dose equivalent Hp(10)" measured in mSv (or μSv) by the electronic dosimeters.

The analysis of patient dose indicators can be made for interventional radiology:

- For the "full procedure" using the relevant dosimetric quantities P_{KA} and $K_{a,r}$. Sometimes other parameters such as fluoroscopy time and the number of images may also be used.
- For the "different radiation events" produced during the procedures. The events used for FGIP are: fluoroscopy, cine, digital subtraction angiography (DSA) and cone beam computed tomography (CBCT). We use the term "radiation event" each time the operator presses the pedal for fluoroscopy or for other image mode acquisitions. A radiation event is defined as a single use of radiation during a continuous length of time as part of a procedure.

These dosimetric indicators for patients are compared with DRLs, or trigger levels, and the radiation events analysis is used for optimisation when individual patient dose indicators for some of the procedures are considered too high.

Information on occupational doses is sent in real-time, and wirelessly, to the "hubs" located in the interventional rooms, and from there, to the DOLQA for analysis, together with patient dose values. Occupational doses measured by the electronic personal dosimeters during the different radiation events are also archived to produce the "occupational registries".

In addition to the management of occupational doses by the DOLQA system, a smartphone application is offered to the interventionists in our hospital. The application is able to present the information on personal doses received and recorded by a server, which sends the electronic dosimeters to a hub in each laboratory, reviews their occupational records and also produces alerts for the users.[21]

Occupational doses and occupational dose rates can also be shown in real time, as the patient dose indicators, on a dedicated screen to the interventionists inside the catheterisation rooms.

Optimisation is made as an integrated approach, by auditing different sets of parameters for individual procedures: patient dose indicators, occupational dose values, the ratio between occupational doses and the doses measured by the reference

dosemeter at the C-arm, and the ratio between occupational and patient dose values.

Dosimetric parameters selected for the audited patient and occupational exposures

The relevant information managed by the DOLQA system to help in the audit of patient exposures, in addition to the date, time and the interventional room, is:

Identification of the interventional procedure and clinical indication (if available).
Age and gender.
Access (femoral or radial).
Kerma area product P_{KA} (for the full procedure or each of the radiation events).
Air kerma at the "patient entrance reference point" $K_{a,r}$ (for the full procedure or each of the radiation events).
Fluoroscopy time and number of acquired images.

More data are available for the radiation events analysis, in addition to the P_{KA} and $K_{a,r}$ per event, such as kVp, mA, X-ray beam filtration, C-arm angulation and rotation, collimation, etc.

For occupational exposures, the parameters managed to help in optimisation, in addition to the date, time, and the interventional room, are:

Electronic dosemeter identification, linked to an operator as the use of the dosemeter is personal and non-transferable.
Personal dose equivalent Hp(10) per procedure (or per radiation event).
Percentage (ratio) of this occupational dose value in relation to the value measured by the reference dosemeter at the C-arm.
P_{KA} (for the full procedure or each of the radiation events).
$K_{a,r}$ (for the full procedure or each of the radiation events).
Ratio between the dose value measured by the electronic dosemeter and the kerma area product for the procedure (μSv/Gy.cm^2).

Figure 1 summarises the main patient and staff dose indicators managed by the DOLQA system, to follow the ICRP recommendation for an integrated optimisation approach.

Figure 2 shows the position of the reference dosemeter at the C-arm and the box containing the electronic dosemeter.

Figure 3 summarises the alerts selected in our hospital, considered as "threshold values" (for patients and staff) to audit some of the interventional procedures. The audit may be initiated by one or several "alerts" for abnormal values in patient or occupational doses.

These values should be "adapted" to the different interventional rooms. High values of P_{KA} and $K_{a,r}$ are more frequent (in our hospital) in interventional radiology procedures than in the cardiology rooms. This is one of the reasons for using a range of values for the alerts, as shown in Figure 3. Of course, the complexity of some procedures and the radiation doses involved in a university hospital may be higher than in other centres.

It should be noted that in 2009, the Society of Interventional Radiology (SIR) and the Cardiovascular and Interventional Radiology Society of Europe (CIRSE) suggested in the "Guidelines for Patient Radiation Dose Management",[10] the higher values as thresholds for patient follow-up: 5000 mGy and 500 Gy.cm^2. But in Figure 3, the suggested alerts are for auditing the procedures and suggesting optimisation actions, and not for clinical follow-up.

In addition to the main dosimetric indicators for patients (P_{KA} and $K_{a,r}$), the two parameters selected to audit occupational protection, identifying the need for potential optimisation actions, are (Figure 3):

(1) Values of personal dose equivalent Hp(10) per procedure (measured over the protective apron) for the different interventionists (and nurses, in cardiology rooms).

Figure 1. Main patient dose and occupational dose indicators for audit and optimisation.

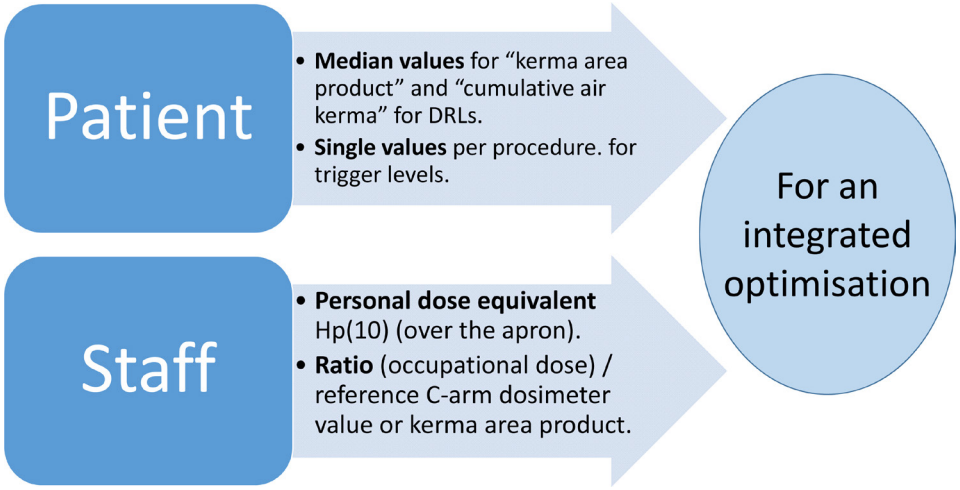
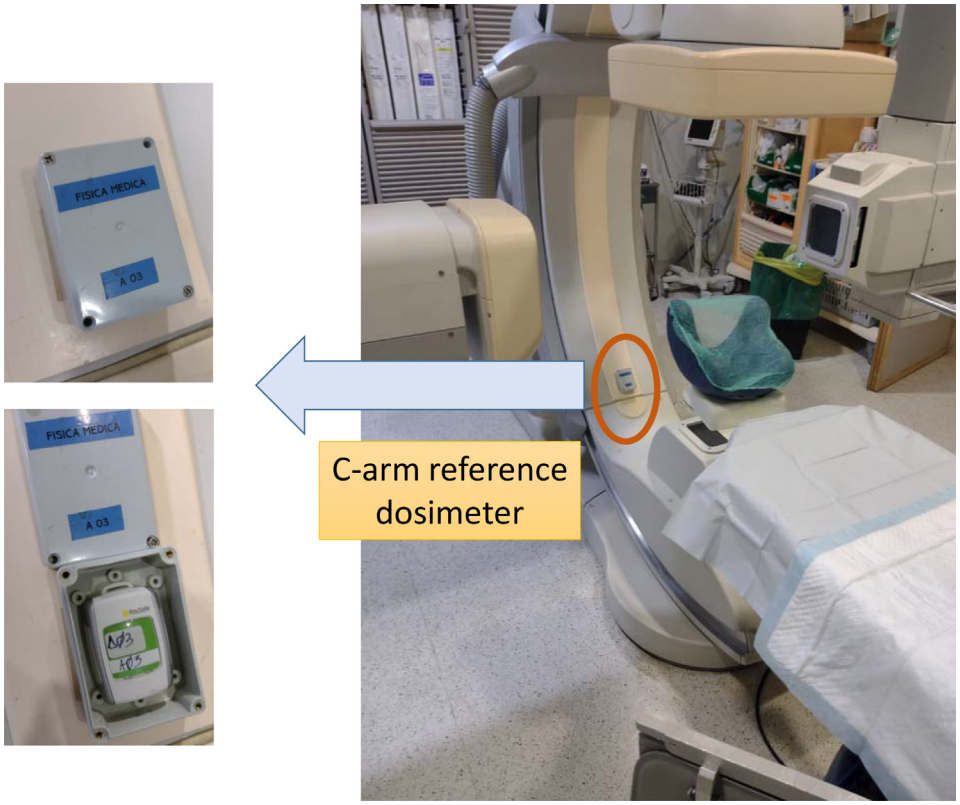


Figure 2. Position of the C-arm reference dosemeter.



(2) The ratio between personal occupational doses and the dose values measured by the reference C-arm dosemeter, or the ratio between occupational dose values and the P_{KA} values µSv/(Gy.cm^2).

For some abnormal values (alerts values indicated in Figure 3), the radiation events may also be analysed (using graphical displays or Excel files) to identify the events responsible for the highest staff doses.

RESULTS AND DISCUSSION

Around 4500 FGIP with 277,000 radiation events and around 8000 occupational registries for full procedures have been managed. The dosimetric results from electronic dosimeters (for occupational dose values and for the C-arm reference dosimeters) can be analysed for the different radiation events. For 3043 procedures, the full set of data (for patients and staff) was available. Patient and staff doses (for 11 cardiologists, 7 radiologists and 8 nurses) have been processed. We excluded procedures with incomplete data on occupational dose registries for electronic personal dosimeters. Passive thermoluminescent dosimeters have always been used by the staff, but they are not allowing the analysis of occupational doses for individual procedures. This section presents the results in the described methodology helping in the integrated optimisation using the alerts for high values of patient and/or occupational doses.

Figure 3. Local alerts selected to audit dosimetric indicators for patients and staff.

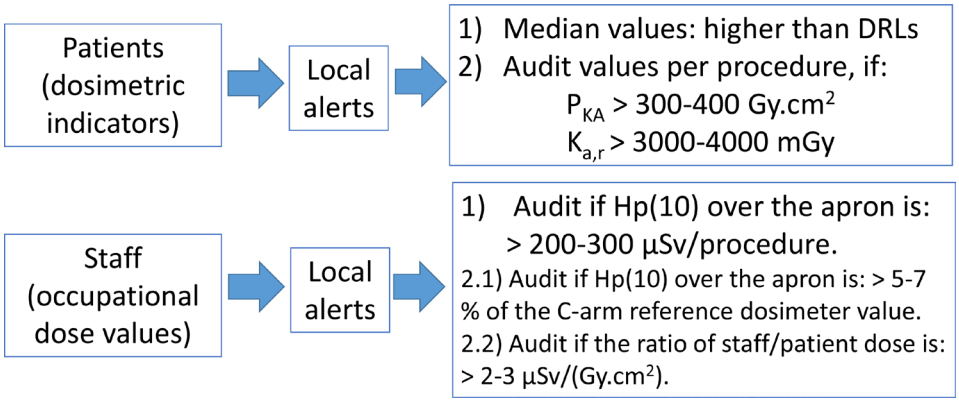
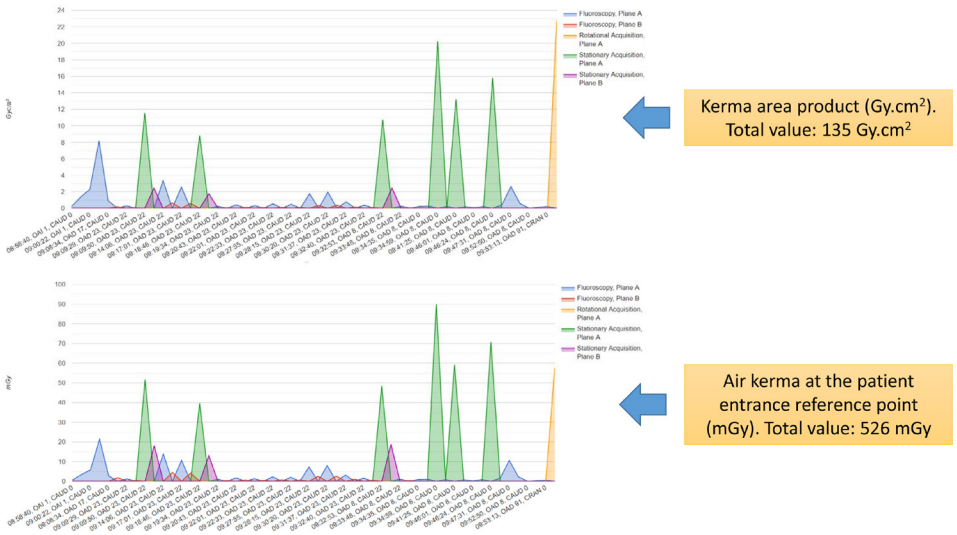


Figure 4. Example of a graphical presentation for the "Air Kerma Area Product" (in Gy.cm^2) and the "Air Kerma at the patient entrance reference point" (in mGy) for the radiation events in a cerebral angiography.



Patient protection optimisation

The optimisation actions based on patient dose indicators are well known. As indicated in Figure 1, a periodic audit of the median value of P_{KA} and $K_{a,r}$ for procedures with the same clinical indications may be made by the DMS and compared with the local or national DRLs, alerting to the need for some corrective actions. Single values per procedure are also part of the audit. In this figure, the importance of managing occupational doses for an integrated optimisation as recommended by the ICRP is also indicated.

The selection of some individual procedures with high-dose values is made to identify the cases of potential skin injuries and the decision for a clinical follow-up. Several DMSs include additional options to calculate the peak skin dose and/or the skin dose maps,[20,22,23] very helpful in deciding the need for a clinical follow-up for potential skin injuries. Figure 2 shows the local alert values used in our hospital for the analysis of some of the procedures to decide if optimisation actions could be necessary.

This process may require an analysis of the radiation events to identify whether the radiation events of cine, DSA or CBCT were all necessary and if some of them were too large (with too many images). The graphical display of the radiation events offered by the DOLQA (Figure 4 corresponding to the neuroradiology biplane X-ray system) may be very useful for these audits and to identify the contribution of the different radiation events in the values of P_{KA} and $K_{a,r}$. The CBCT (rotational acquisition, plane A) is made, in this case, at the end of the procedure. The C-arm angulations and the time of the events are also included in the figures to help in the audit. The impact of the collimation and the different C-arm angulations should also be considered for the optimisation to avoid overlapping of the radiation fields on the same area of the skin.

Occupational protection optimisation

Occupational doses should also be analysed if personal electronic dosimeters are used.[24] Occupational doses per procedure may also be processed by the DMS to detect the lack of proper occupational protection (high occupational doses for some radiation events) and the need to implement, in some cases, corrective actions.

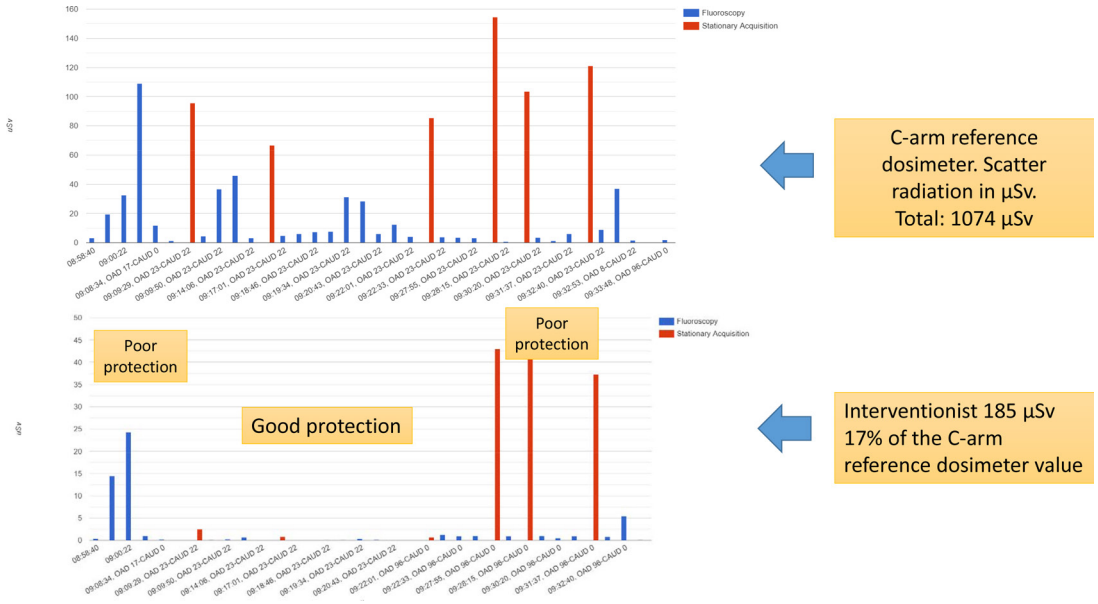
High doses per procedure at the C-arm reference dosemeter usually correspond to high values of P_{KA}. But C-arm angulation, collimation and the X-ray beam quality (kV and filtration) also have a relevant impact on the level of scatter radiation.

For complex procedures, occupational doses should be audited by the professionals involved in the procedures. If staff are not properly protected during some of these procedures, occupational doses may be unnecessarily high and professionals should be alerted to improve their personal radiation protection.

A practical way to avoid unnecessary occupational exposure is to audit the procedures with high personal occupational dose values and the ratio between these personal doses and the dose measured by the reference dosemeter. If this ratio is higher than a few percentage points (more than 5–7% of the C-arm reference dosemeter) (Figures 2 and 3), the professionals should be alerted to improve their occupational protection.

The ratio between personal occupational doses and the P_{KA} values for patients is another useful parameter to avoid unnecessary staff exposures.[8] This ratio depends on many factors (C-arm angulation, collimation, kV and filtration, etc.). But high values of μSv/(Gy.cm^2) should be investigated to improve occupational radiation protection. The local value for the alerts adopted in our hospital is 2–3 μSv/(Gy.cm^2) (Figure 3). Higher values may suggest improper use of the ceiling suspended screen.

Figure 5. Example (for the same cerebral arteriography procedure) of the Hp(10) in µSv, measured by the C-arm reference dosemeter and by the dosemeter of the first interventionist operator for the different radiation events.



When some of these alerts exist, for several procedures and interventionists, it may be necessary to audit the occupational doses for those professionals in detail (looking at the radiation events during the procedures) and give specific recommendations to improve the practice or to consider alternatives. Sometimes the advice for a better use of the ceiling suspended screen (or other similar shielding) is enough to optimise occupational protection.

Figures 5 and 6 show an illustrative example of an alert on occupational doses corresponding to the cerebral angiography procedure shown in Figure 4, with a quite standard patient dose value.

This is one example of the "alert" produced just for occupational exposure but not from the patient's dose. In Figure 5, we can see the values of the scatter radiation (in µSv) for the different radiation events in the interventional procedure used as example. At the bottom of the figure, we can see the occupational doses measured by the personal electronic dosemeter of the main operator (worn over the lead apron). All the dosimetric indicators in Figure 4 seem normal: 135 Gy.cm^2 and 526 mGy for patient dose indicators. The occupational dose value of 185 µSv for the first operator is quite high but not high enough to generate an alert according to the hospital's current thresholds (Figure 3). But the

Figure 6. Example (for the same cerebral arteriography procedure) of the Hp(10) rate in mSv/h, measured by the C-arm reference dosemeter and by the dosemeter of the first interventionist operator for the different radiation events.

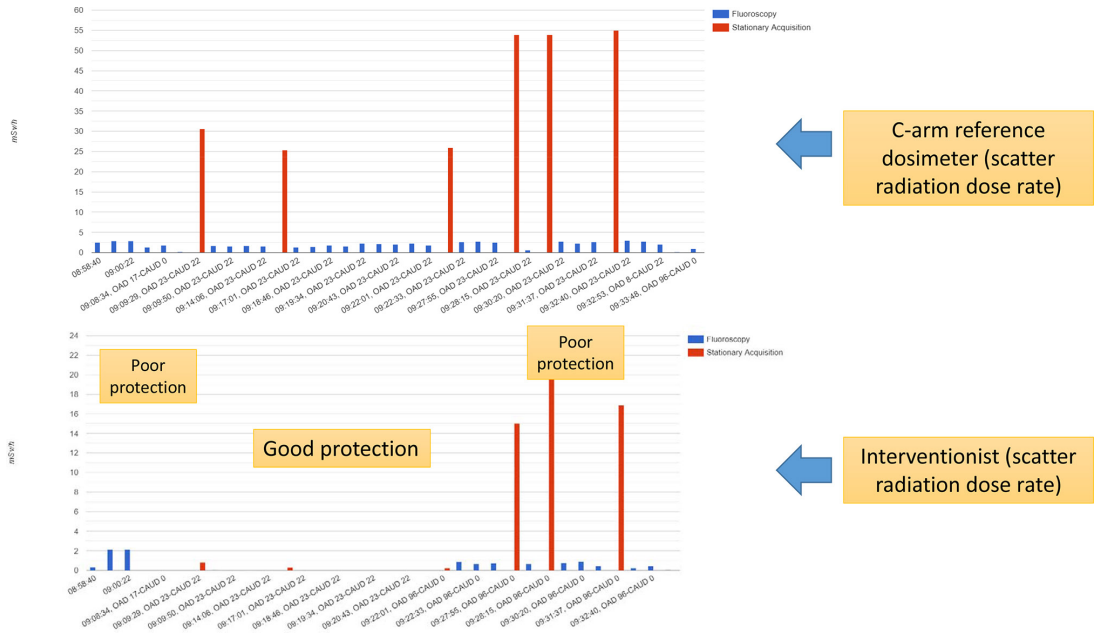


Table 1. Percentage of procedures (per doctor) needing to improve the occupational protection. The percentage refers to occupational dose values (over the lead apron) higher than 5% of the reference C-arm dosemeter value

Area of activity	Number of doctors	Number of procedures (per doctor) with completed set of occupational dose values	Percentage of procedures (per doctor) needing optimisation in occupational protection[a]
Interv. Cardiology	11	38–218	6–44%
Interv. Radiology	4	170–377	49–79%
Interv. Neuroradiol.	3	64–141	13–22%

[a]Percentages of occupational dose values (over the lead apron) higher than 5% of the reference dosemeter value.

ratio between the operator dose of 185 μSv and the value of the C-arm reference dosemeter (1074 μSv) is 17% and this generates the alert which suggests improving the protection when using the ceiling suspended screen.

Note the lack of enough protection in Figures 5 and 6, at the beginning and the end of the procedure. Interventionist doses in some fluoroscopy and DSA events are only reduced by around 25–40% in comparison with the reference non-protected-dosimeter at the C-arm.

For some interventionists, we found that the use of the protective screen could be improved for a relatively high number of procedures. Fortunately, they also use protective goggles, but improvement in the use of the ceiling suspended screen (or other equivalent shielding) is necessary.

Table 1 shows a summary of the analysis for the 18 interventionists followed during 2021 with electronic dosimeters. The percentage of procedures (per doctor) needing optimisation in occupational protection, derived from the alert that occupational dose values are higher than 5% of the reference dosemeter value, is between 6 and 79%, being higher in interventional radiology, (vascular room) probably due to the excessive number of procedures done with difficulty in using the protective screen.

But the occupational protection indicators for the five interventional rooms audited during 2021 are reasonably good in our hospital in comparison with published results.[25] Table 2 shows median and third quartile values per procedure of the Hp(10) for the C-arm reference dosemeter and the doctors (and nurses in cardiology rooms).

Note that the "Cardio 5" room has an X-ray system updated by Philips to the "Clarity" option, to reduce patient doses and improve image quality, but with a certain increase of scatter dose per unit of P_{KA} due to the filtration used for the cine acquisitions.[26] The median values in μSv/(Gy.cm^2) at the C-arm reference dosemeter, with a sample of 323 procedures resulted in 18.8 μSv/(Gy.cm^2) in this room. The median values per procedure of Hp(10) for doctors were 10–12 μSv in cardiology and around 1 μSv for nurses. This value is higher for interventional radiologists (16.6 μSv) and lower for neuroradiology (8.9 μSv). The median value of Hp(10) for the C-arm

Table 2. Results during 2021 of the electronic dosimeters dose values in μSv per procedure (medians and third quartiles) for the five interventional rooms analysed. Sample sizes are included. Values for doctors, nurses and C-arm, are included

X-ray room	Dosimeters	N	μSv/proced. (median)	μSv/proced. (third quartile)	μSv/(Gy.cm^2) (median)	μSv/(Gy.cm^2) (third quartile)
Cardio 3	C-arm	711	640.5	1064.8	11.1	13.1
	Doctors	602	11.7	26.3		
	Nurses	646	1.0	3.9		
Cardio 4	C-arm	673	525.1	873.7	8.8	10.6
	Doctors	637	12.1	31.3		
	Nurses	605	0.9	4.5		
Cardio 5	C-arm	323	595.3	1052.8	18.8	20.9
	Doctors	657	9.9	26.8		
	Nurses	416	0.9	2.6		
Vascular 1	C-arm	925	148.2	602.7	15.3	17.7
	Doctors	1059	16.6	43.8		
Neuro 1	C-arm	411	656.0	1400.0	8.3	9.2
	Doctors	378	8.9	26.5		

reference dosemeter is much lower for the vascular room (148 μSv in comparison to the 500–650 μSv in the other rooms) due to the large number of very short procedures done in that room. The third quartile in Table 2 offers information on the dispersion of the values in the analysed samples. It should be noted that in many procedures, there are substantial differences in occupational doses between the first operator and the other doctors (sometimes, residents in university hospitals), and median and third quartile values may not be fully representative of some high exposures for the first operators during some procedures. The importance of the "alerts" and audits for optimisation of the occupational protection for individual procedures is relevant for radiation safety.

The median values of the ratio between the reference dosemeter value and the kerma area product (μSv/Gy.cm^2) for individual procedures are different for the five interventional rooms, in part due to the position of the dosemeter at the C-arm, the different use of collimation, and the quality of the used X-ray beam (much higher in cardio room five with the "clarity" option). But in this room, the patient doses (for similar procedures) are much lower than in the other cardiology rooms (3 and 4) as well as the median values of occupational doses per procedure for interventionists (9.9 μSv) being lower than in rooms 3 and 4 (11.7 and 12.1 μSv). Usually, some of the most complex cardiology procedures are sent to room five to profit from the low patient dose protocols in that room.

In any case, the priority should always be the clinical outcomes of the procedures and any potential reduction of patient and staff doses should be compatible with this priority.[27]

CONCLUSIONS

For patients, the DMS allows, with a set of "alerts", detecting whether median values are over the DRLs and to identify high doses for individual procedures for potential skin radiation injuries.

For occupational protection, the audit of personal dose equivalent per procedure and the ratio between occupational dose and the reference C-arm dosemeter value, or kerma area product, allows detecting improper staff protection, suggesting optimisation actions.

The main advantage of this integrated approach is the capacity to improve radiation safety for patients and workers together. Close cooperation between the team of medical physics experts, radiologists, cardiologists, radiographers and nurses is recommended for good exploitation and quality control of the system.

LIMITATIONS

Not all the data in the DOLQA system for interventional procedures have been used due to the fact that the results of occupational electronic dosimetry were not available for all the procedures and some dosimeters were removed from use in 2021 due to failure.

REFERENCES

1. López PO, Dauer LT, Loose R, Martin CJ, Miller DL, Vañó E, et al. ICRP publication 139: occupational radiological protection in interventional procedures. *Ann ICRP* 2018; **47**: 1–118. https://doi.org/10.1177/0146645317750356
2. 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? *Catheter Cardiovasc Interv* 2010; **76**: 826–34. https://doi.org/10.1002/ccd.22670
3. Ciraj-Bjelac O, Rehani M, Minamoto A, Sim KH, Liew HB, Vano E. Radiation-induced eye lens changes and risk for cataract in interventional cardiology. *Cardiology* 2012; **123**: 168–71. https://doi.org/10.1159/000342458
4. Jacob S, Boveda S, Bar O, Brézin A, Maccia C, Laurier D, et al. Interventional cardiologists and risk of radiation-induced cataract: results of a french multicenter observational study. *Int J Cardiol* 2013; **167**: S0167-5273(12)00560-8: 1843–47: . https://doi.org/10.1016/j.ijcard.2012.04.124
5. 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**: S1051-0443(12)01102-5: 197–204: . https://doi.org/10.1016/j.jvir.2012.10.016
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**: 151–60. https://doi.org/10.1007/s00270-015-1207-z
7. Sailer AM, Vergoossen L, Paulis L, van Zwam WH, Das M, Wildberger JE, et al. Personalized feedback on staff dose in fluoroscopy-guided interventions: a new era in radiation dose monitoring. *Cardiovasc Intervent Radiol* 2017; **40**: 1756–62. https://doi.org/10.1007/s00270-017-1690-5
8. Sailer AM, Paulis L, Vergoossen L, Kovac AO, Wijnhoven G, Schurink GWH, et al. Real-time patient and staff radiation dose monitoring in IR practice. *Cardiovasc Intervent Radiol* 2017; **40**: 421–29. https://doi.org/10.1007/s00270-016-1526-8
9. Loose RW, Vano E, Mildenberger P, Tsapaki V, Caramella D, Sjöberg J, et al. Radiation dose management systems-requirements and recommendations for users from the ESR eurosafe imaging initiative. *Eur Radiol* 2021; **31**: 2106–14. https://doi.org/10.1007/s00330-020-07290-x
10. Stecker MS, Balter S, Towbin RB, Miller DL, Vañó E, SIR safety and health committee; CIRSE standards of practice committee. Guidelines for patient radiation dose management. *J Vasc Interv Radiol* 2009; **20**: S263–73. https://doi.org/10.1016/j.jvir.2009.04.037
11. Jaschke W, Bartal G, Martin CJ, Vano E. Unintended and accidental exposures, significant dose events and trigger levels in interventional radiology. *Cardiovasc Intervent Radiol* 2020; 1114–21. https://doi.org/10.1007/s00270-020-02517-2
12. ICRP Publication 93. Managing patient dose in digital radiology. Ann ICRP. 2004;34(1):1-73. https://doi.org/10.1016/j.icrp.2004.02.001.
13. Vañó E, Miller DL, Martin CJ, Rehani MM, Kang K, Rosenstein M, et al. ICRP

publication 135: diagnostic reference levels in medical imaging. *Ann ICRP* 2017; **46**: 1–144. https://doi.org/10.1177/0146645317717209
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**: 1077–88. https://doi.org/10.1088/1361-6498/aad429
15. Vano E, Sanchez Casanueva R, Fernandez Soto JM, Bartal G. Challenges in occupational dosimetry for interventional radiologists. *Cardiovasc Intervent Radiol* 2021; **44**: 866–70. https://doi.org/10.1007/s00270-020-02725-w
16. European Council Directive 2013/59/EURATOM on basic safety standards for protection against the dangers arising from exposure to ionising radiation. 2014. Available from: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2014:013:0001:0073:EN:PDF
17. Ten JI, Fernandez JM, Vaño E. Automatic management system for dose parameters in interventional radiology and cardiology. *Radiat Prot Dosimetry* 2011; **147**: 325–28. https://doi.org/10.1093/rpd/ncr350
18. Vano E, Ten JI, Fernandez-Soto JM, Sanchez-Casanueva RM. Experience with patient dosimetry and quality control online for diagnostic and interventional radiology using DICOM services. *AJR Am J Roentgenol* 2013; **200**: 783–90. https://doi.org/10.2214/AJR.12.10179
19. Fernandez-Soto JM, Ten JI, Sanchez RM, España M, Pifarre X, Vano E. Benefits of an automatic patient dose registry system for interventional radiology and cardiology at five hospitals of the madrid area. *Radiat Prot Dosimetry* 2015; **165**: 53–56. https://doi.org/10.1093/rpd/ncv043
20. Vano E, Fernández JM, Ten JI, Sanchez RM. Benefits and limitations for the use of radiation dose management systems in medical imaging. Practical experience in a university hospital. *Br J Radiol* 2022; **95**: 1133. https://doi.org/10.1259/bjr.20211340
21. Sánchez RM, Fernández D, Vañó E, Fernández JM. Managing occupational doses with smartphones in interventional radiology. *Med Phys* 2021; **48**: 5830–36. https://doi.org/10.1002/mp.15148
22. Greffier J, Grussenmeyer-Mary N, Hamard A, Goupil J, Miller DE, Cayla G, et al. Clinical evaluation of a dose management system-integrated 3D skin dose map by comparison with radiochromic films. *Eur Radiol* 2020; **30**: 5071–81. https://doi.org/10.1007/s00330-020-06877-8
23. Krajinović M, Kržanović N, Ciraj-Bjelac O. Vendor-independent skin dose mapping application for interventional radiology and cardiology. *J Appl Clin Med Phys* 2021; **22**: 145–57. https://doi.org/10.1002/acm2.13167
24. Vano E, Sanchez RM, Fernández FS. Helping to know if you are properly protected while working in interventional cardiology. *J Radiol Prot* 2020; **40**(4). https://doi.org/10.1088/1361-6498/abc325
25. Kim KP, Miller DL, Berrington de Gonzalez A, Balter S, Kleinerman RA, Ostroumova E, et al. Occupational radiation doses to operators performing fluoroscopically-guided procedures. *Health Phys* 2012; **103**: 80–99. https://doi.org/10.1097/HP.0b013e31824dae76
26. Salinas P, Sanchez-Casanueva RM, Gonzalo N, A Gil J, Salazar CH, Jimenez-Quevedo P, et al. Dose-reducing fluoroscopic system decreases patient but not occupational radiation exposure in chronic total occlusion intervention. *Catheter Cardiovasc Interv* 2021; **98**: 895–902. https://doi.org/10.1002/ccd.29253
27. Bartal G, Vano E, Paulo G. Get protected! recommendations for staff in IR. *Cardiovasc Intervent Radiol* 2021; **44**: 871–76. https://doi.org/10.1007/s00270-021-02828-y