Physica Medica 68 (2019) 104–111

Contents lists available at ScienceDirect

Physica Medica

journal homepage: www.elsevier.com/locate/ejmp

Original paper

Conversion factors to estimate effective doses from kerma area product in interventional cardiology. Impact of added filtration

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ARTICLE INFO

Keywords:
Interventional cardiology
Patient dose
Effective dose
Population dose
Filtration

ABSTRACT

There is a large variation in the factors used to estimate effective doses from kerma area product (KAP) for interventional cardiology. These factors are required to estimate population doses. This paper presents the results for this conversion factor for cardiac procedures using tissue weighting factors of ICRP-103 and the impact of the added copper filtration in the X-ray beam.

The data from 925 cardiac procedures and 75,347 radiation events were collected from two angiography laboratories using the DICOM Radiation Dose Structured Reports (RDSR). Effective doses were calculated with Monte Carlo software and the dosimetric, technical and geometrical information included in the RDSR.

In one laboratory, with an X-ray system without Cu filtration for the cine runs, a factor of 0.21 ± 0.05 mSv/(Gy·cm^2) was obtained. In other laboratory, incorporating a patient dose reduction technique, and 0.4 mm of Cu filtration for cine runs, the conversion factor was 0.29 ± 0.05 mSv/(Gy·cm^2). The analysis of the radiation events for the different Cu filtrations (0.0; 0.1; 0.4 and 0.9 mm) resulted in conversion factors of: 0.16; 0.27; 0.34 and 0.40 mSv/(Gy·cm^2) respectively.

The estimation of effective and population doses from KAP should take into account the Cu filtration in the X-ray beam. For the X-ray system with patient dose reduction technique, using 0.4 mm Cu for cine runs, the global conversion factor increased by 38%, from 0.21 to 0.29 mSv/(Gy·cm^2) in comparison to the standard X-ray system with a protocol that did not include copper filtration for cine acquisitions.

1. Introduction

The X-ray systems used for interventional procedures are able to give patient exposure indexes during and at the end of the procedures. In the most recent models, the X-ray systems are able to transfer this dosimetric and other technical and geometrical information to the DICOM radiation dose structured reports (RDSR).

The dosimetric data, kerma area product –KAP– and air kerma –AK– at the patient entrance reference point [1], are used for optimisation of the radiation protection of patients. Now, with the information contained in the RDSR (kV, filtration, C-arm angulation, radiation field size, etc) the optimisation actions may be improved. For specific clinical indications, their median values should be periodically compared with the diagnostic reference levels (DRLs) [2].

Population doses are estimated using the frequency of the procedures and the quantity effective dose. The Monte Carlo software [3] allows organ and effective doses to be calculated from the primary dosimetric quantities reported by the X-ray systems, from all the information on the X-ray beam quality (kV and filtration) and from other geometrical and technical factors.

According to the recommendations of the International Commission on Radiological Protection (ICRP), effective doses should not be used to estimate individual radiation risks to patients but may be useful to compare the relative risks when different imaging procedures with different modalities (e.g. X-ray catheterization, computed tomography and nuclear medicine) are performed on the same patient [4,5].

The new European Directive on Basic Safety Standards [6] requires patient dose audits and the use of DRLs for optimisation, and in addition, this regulation requires that “population doses derived from medical exposures be estimated for radiodiagnostic and interventional radiology”. Such a requirement makes it necessary to estimate effective doses and the frequency of the procedures.

The UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) collects and periodically publishes the worldwide

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https://doi.org/10.1016/j.ejmp.2019.11.013
Received 17 September 2019; Received in revised form 24 October 2019; Accepted 15 November 2019
Available online 25 November 2019

data on population doses arising from medical exposures. The last global report for the data corresponding to the period 1997–2007 was published in 2008 [7] and the next report is expected in 2020.

UNSCEAR recognises that there are some limitations to the survey data as the majority of responses received come from the relatively more developed countries. Principally because of their numerous significant benefits, interventional radiology and cardiology procedures have experienced a dramatic increase in frequency in recent years. The UNSCEAR report of 2008 stated that the average conversion factor to deduce the effective dose from KAP readings for cardiac interventional procedures was 0.17 mSv/(Gy.cm^2) [7].

In 2015, UNSCEAR published in view of the next report, a “User Manual for the Global Survey on Medical Exposures” [8] in which it is indicated that “effective dose estimation is usually performed using simpler methods on the basis of easily measurable dose metrics and the application of conversions coefficients that have been determined through scientific research”.

The factors recommended in this manual for the estimation of effective doses in cardiac interventional procedures were: 0.12 mSv/(Gy.cm^2) for diagnostic coronary angiography and a wide range of factors from 0.20 to 0.28 for percutaneous transluminal coronary angioplasty (PTCA) [8].

In Europe, all the interventional procedures are estimated to contribute 3.5–14%, to the collective dose and the PTCAs, 0.5–3.6% [9]. In the latest European report, published in 2015 [10], the contribution of interventional radiology to the total collective dose in medical imaging in Europe was estimated 8–9% with a mean value in frequency of 0.6%. For coronary angiography and coronary angioplasty, in many countries, the effective dose is being estimated by multiplying the KAP by 0.2 mSv/(Gy.cm^2), a factor recommended by the European Guidelines for adult patients in IC (interventional cardiology) [9].

In Spain, the fraction of the collective dose per million inhabitants derived from IC was 34 man-Sv (1600 man-Sv in Spain with 46.5 million inhabitants). The frequency of the IC procedures in Spain is 0.66% from the total medical procedures with X-rays, and IC represents 4% of the X-ray collective dose. These estimations result from the information on frequencies of examinations sourced from the Spanish Society of Cardiology and the patient dose values obtained by the national programme on patient dose DOCCACI [11].

The patient dose management systems already introduced in many hospitals allow to collect the dosimetric data, together with other technical details and geometrical data automatically for each radiation event (fluoroscopy and cine runs) of the interventional procedures. Consequently, a more detailed Monte Carlo calculation can be made to estimate organ and effective doses for a large number of patients.

Another importance issue is that some new X-ray systems dedicated to interventional procedures are implementing patient dose reduction techniques with different X-ray beam qualities (higher Cu filtration) and with advanced post-processing of the images, which may lead to a substantial variation in the conversion factor to estimate effective doses.

It seems appropriate to revisit and update these conversion factors. The aims of this paper are:

- To calculate the conversion factors (using all the information contained in the RDSR for each of the radiation events), to estimate effective doses from KAP values, using a large number of cardiac procedures and Monte Carlo software.
- To evaluate the impact of the added copper filtration in the X-ray beams on these conversion factors, and to give practical advice for the evaluation of the collective doses derived from IC.

2. Materials and method

We have used the data of all the interventional cardiac procedures performed during the year 2018 in two interventional cardiology laboratories in a large university hospital in Madrid.

The two cardiac laboratories are equipped with Philips Allura interventional systems: room 3 (used for the most standard diagnostic and therapeutic procedures) with the Allura X-PER X-ray system, and room 5, with a “Clarity” version of the Allura system (the new patient dose reduction system from Philips). This X-ray system has a specific hardware and software with a new post-processing for imaging, allowing a significant reduction in patient doses [12–14]. Both systems have the same imaging detector (Trixel P4700 154 µm) and quite similar X-ray tube and generator, but they work with different default protocols. While the Xper system has a fluoroscopy mode (the default mode) with 0.9 mm Cu + 1 mm Al of additional filtration and the cine mode with no additional filtration, the new Clarity system uses a default imaging protocol with 0.4 mm of Cu for fluoroscopy and cine, adapted by the manufacturer to the new imaging post-processing. In any case, in both systems, the operator can select other protocols with higher dose modes and with different filtrations if required, to improve image quality, but this only occurs in specific cases.

Data from 925 cardiac procedures and 75,347 radiation events have been collected by a homemade automatic patient dose management system (named DOLIR) using the DICOM RDSR to collect and process the individual data of all the radiation events [15,16]. The Monte Carlo software later processed these data to calculate organ and effective doses [3] taking into account the kV and added filtration (and other technical and geometrical parameters included in the RDSR).

The values of KAP transferred by the X-ray system to the patient dose reports (or to the RDSR in these two rooms) are periodically validated by the Medical Physics service of the San Carlos University Hospital. The attenuation factor of the table and mattress is also measured for the different operation protocols. This attenuation is usually not considered to set the DRLs and to audit patient dose values but should be taken into account when KAP is used to estimate organ and effective doses as highlighted in a recent paper on European diagnostic reference levels for cardiology [17].

The attenuation factor is typically in the range of 0.6–0.9 for most of the interventional cardiology laboratories and operation protocols, depending on the X-ray beam qualities and C-arm angulations in cardiology [18]. During a national programme held in Spain in cooperation with the Spanish Society of Cardiology (DOCCACI programme) and involving 14 hospitals and 26 interventional cardiology laboratories, the average couch and mattress attenuation obtained was 0.75 ± 0.07 [19].

Patient organ doses and effective doses were calculated using the PCXMC 2.0 software [3], a Monte Carlo software developed by STUK (Radiation and Nuclear Safety Authority in Finland). The organ and tissue absorbed doses were calculated as well as the effective doses, using the tissue weighting factors of ICRP 103 [4]. The calculations were made with the Autocalc-sheet application. This application helps define the examination parameters, calculate doses and process additional data in the Excel spreadsheet. The calculation was performed for each of the 75,347 radiation events (corresponding to 925 cardiac interventional procedures) and the results of the corresponding events, were added to obtain the dose values for each of the full procedures.

The examination parameters used from the DICOM RDSR collected by the DOLIR dose management system, were: projection; projection angle; patient number; patient height; patient weight; patient age; X-ray tube voltage (kV); filtration (mm Al); additional filter (mm Cu); focus-reference point distance -FRD- (cm); X-ray beam width (cm at FRD); X-ray beam height (cm at the FRD); coordinates of a point inside the phantom centred at phantom heart, through which the central axis of the X-ray beam is directed (Xref, Yref and Zref); arms in phantom (1 or 0); and input dose value. The software allows the use of incident air kerma (at FRD) or the KAP for the calculations. In our case, the reference point is the isocentre (where the heart should be positioned).

We have also analysed independently the conversion factors mSv/(Gy.cm^2) for the radiation runs using the different added copper

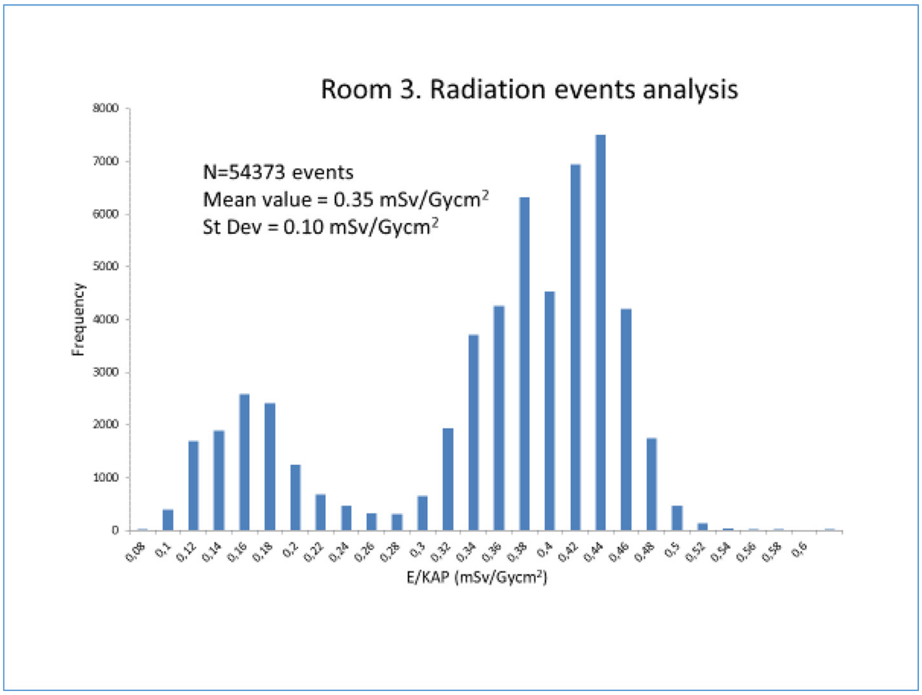

Fig. 1. Frequency analysis of the conversion factors by radiation events in the standard cardio room.

filtrations to estimate the impact of the filtration.

These results for the different filtrations allow refining, if appropriate, the global conversion factors used in other hospitals, if filtrations used for the operation protocols are known.

3. Results

Figs. 1 and 2 present the results for catheterisation room 3 (standard X-ray system) for all the clinical procedures (coronary angiographies and PTCAs) performed during 2018. There are, of course, in the sample, procedures with different complexity levels, with different percentages of fluoroscopy and cine modes and patients with different weights. But the sample is large enough (54,373 radiation events and 758 procedures) to consider the conversion factor calculated (ratio between effective doses and KAP) as representative of the practice in that catheterisation laboratory.

In Fig. 1, the results of the analysis of the radiation events show a bimodal distribution with a first peak around 0.16 mSv/(Gy.cm^2) corresponding to the cine runs (without copper filtration in all the protocols used in this catheterisation room number 3). A second peak around 0.40 mSv/(Gy.cm^2) corresponds to the low fluoroscopy mode used in this room (with 0.9 mm of Cu of added filtration).

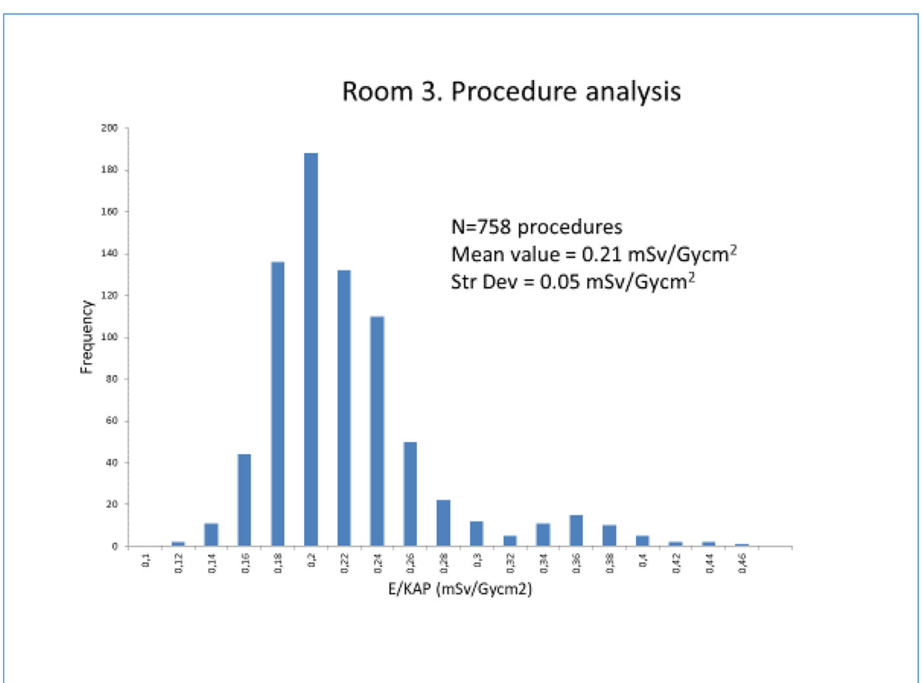

Fig. 2. Frequency analysis of the conversion factors by procedures in the standard cardio room.

Table 1
Conversion factors to effective dose from KAP by Cu filtration, in a cardiology room with a conventional X-ray system.

Data from room 3			
Additional filter (mm Cu)	Number of radiation events from the RDSR	Mean value mSv/Gy.cm^2	St Dev mSv/Gy.cm^2
0.00	11,491	0.16	0.04
0.10	356	0.27	0.06
0.40	1,796	0.34	0.05
0.90	40,730	0.40	0.09
Total	54,373		

Table 1 gives the details of the number of events for the different Cu filtrations: 11,491 without filtration, corresponding to the cine events in this room 3, and 40,730 events with 0.9 mm Cu corresponding to the events of low fluoroscopy mode (the default mode for fluoroscopy). The other low number of events with added filtration of 0.1 and 0.4 corresponds to a few runs using fluoroscopy modes "medium" and "high". It is important to note that the higher number of events in fluoroscopy (almost fourfold) results in a lower contribution in KAP than the cine mode in an average procedure. In general, cine runs involve a higher KAP than fluoroscopy runs.

Fig. 2 presents the analysis (frequency vs. conversion factor values) in room 3 for all the 758 procedures (with the corresponding fluoroscopy and cine runs for each procedure). The results present a mean value and standard deviation of 0.21 ± 0.05 mSv/(Gy.cm^2). We consider that this value is representative of the clinical practice in that room as it takes into account the different percentages of fluoroscopy and cine (with the corresponding Cu filtrations), the different X-ray beam angulations, and the different kV and KAP values depending on the patient weight and the complexity of the procedures.

Figs. 3 and 4 present similar results for room number 5 equipped with the new X-ray system with the "Clarity" option to reduce patient doses. The most complex interventional cardiac procedures (e.g. total occlusions, structural procedures, etc.) of our cardiovascular institute are performed in this room, as only there is it possible to reduce the KAP values by 40–50% in comparison (for similar procedures) to the standard room number 3 [18,12–14].

Fig. 3 presents the frequency histogram for all the 20,974 radiation events in room 5.

Fig. 4 presents the analysis of the 167 procedures performed in room 5 during the year 2018. The histogram is grouping all the events (fluoroscopy and cine) corresponding to each procedure and the mean value for the conversion factor is much higher than in room 3, basically due to the filtration of 0.4 mm Cu in practically all the cine and fluoroscopy acquisitions in this room.

Table 2 presents the results of the analysis for all the radiation events in room 5 for the different Cu filtrations. Note that most of the events (19,483 out of 20,974) correspond to 0.4 mm Cu added filtration.

Fig. 5 presents the variation of the conversion factor mSv/(Gy.cm^2) with the added filtration in mm of Cu (data from room 3, but very similar and compatible with the results from room 5 as can be seen in tables 1 and 2).

4. Discussion

The conversion factors obtained in this paper may be useful to update the previous existing values obtained several years ago and used by NCRP and UNSCEAR [7–9]. In some cases, the factors in these documents were obtained with small samples and without taking into account the relevant impact of the copper filtration in the X-ray beam more used in the current interventional systems.

Figs. 2 and 4 present global factors for cardiac procedures performed with:

- Standard X-ray system and standard protocols (with copper filtration in fluoroscopy modes and without copper filtration in cine acquisitions): 0.21 ± 0.05 mSv/(Gy.cm^2) in Fig. 2 (room 3).
- The new X-ray system (with dose reduction capability) using 0.4 mm of Cu filtration for fluoroscopy and cine acquisitions: 0.29 ± 0.03 mSv/(Gy.cm^2) in Fig. 4 (room 5).

Tables 1 and 2 offer particular conversion factors obtained from a large number of radiation events (54373 in room 3 and 20,974 in room

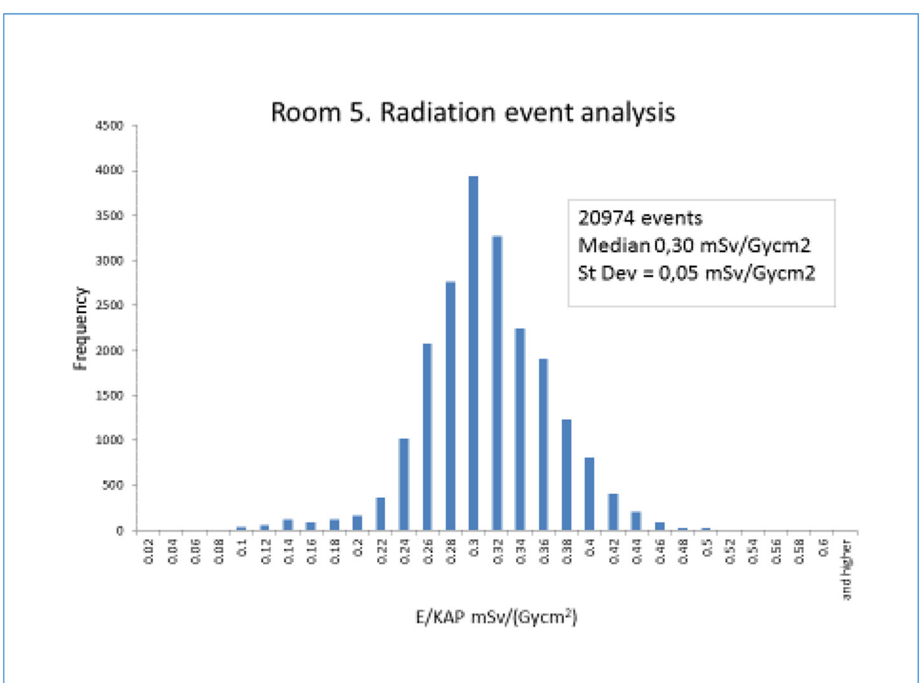

Fig. 3. Frequency analysis of the conversion factors by radiation events in the cardio room with patient dose reduction system (room 5).

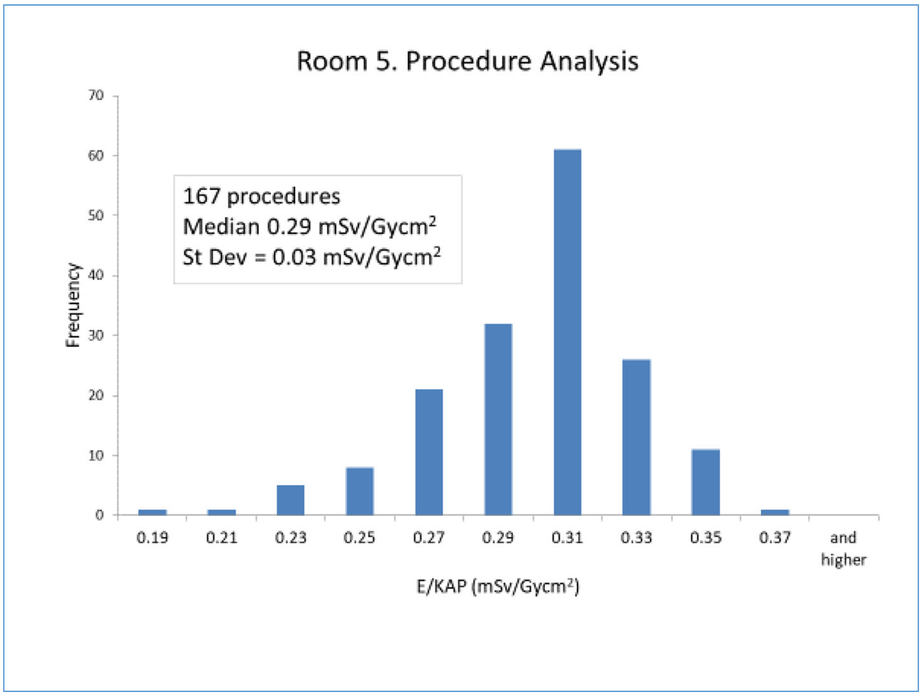

Fig. 4. Frequency analysis of the conversion factors by full procedure in the cardio room with patient dose reduction system (room 5).

Table 2
Conversion factors to effective dose from KAP, by Cu filtration, in a cardiology room with a "dose reduction system" X-ray system.

Data from room 5			
Additional filter (mm Cu)	Number of radiation events from the RDSR	Mean value mSv/Gy.cm^2	St Dev mSv/Gy.cm^2
0.00	440	0.16	0.04
0.10	1,051	0.26	0.05
0.40	19,483	0.31	0.05
Total	20,974		

5) for 0.0; 0.1; 0.4 and 0.9 mm Cu that may help refine the conversion factors in other catheterisation laboratories, for other particular protocols if the copper filtration is known.

X-ray systems with 0.4 mm Cu as added filtration in cine can duplicate the value of the conversion factor from 0.16 to 0.31 mSv/(Gy.cm^2) in comparison to the X-ray systems using the cine without Cu filtration. This should be considered when calculating effective doses for the estimation of population doses.

It should, however, be highlighted that by reducing the skin doses and lowering the values of KAP with the new post-processing of the images, the introduction of copper filtration in interventional X-ray systems has represented large advantages in interventional practices avoiding radiation injuries for complex procedures.

The conversion factors recommended by UNSCEAR in its User Manual [8] are 0.12 for diagnostic coronary angiography and 0.18–0.28 for PTCA (adapted from the values included in the NCRP report 160 [20]). This report includes a large range of conversion factors for cardiology procedures, especially for PTCA, but without including criteria for choosing the best one when estimating the population collective dose derived from the interventional cardiology practice.

The large difference in the conversion factors between diagnostic and therapeutic procedures used in these documents has not been evidenced in our calculations. This difference could result from the use of more cine (without added filtration) than fluoroscopy runs, for diagnostic procedures.

The original values referred in the NCRP report [20] were supported by factors obtained or used by several authors and published long ago. The conversion factors reported were: 0.18 mSv/(Gy.cm^2) measured with a Rando phantom, from Betsou et al. [21]; 0.20 mSv/(Gy.cm^2) from Nefotistou et al. [22], and 0.27 mSv/(Gy.cm^2) with a sample of 270 patients in two Greek hospitals from Delichas et al. [23]. In this last paper, the authors obtained values for diagnostic and therapeutic procedures with similar results; 0.26 and 0.27 respectively mSv/(Gy.cm^2).

Bogaert et al. [24], using a sample of 318 patients in 8 Belgian hospitals, found conversion coefficients of 0.177 mSv/(Gy.cm^2) for systems that do not use any additional copper filtration in cineradiography and 0.207 mSv/(Gy.cm^2) for systems that use additional copper filtration in cineradiography.

The copper filtration has been increased in the current interventional systems used in cardiology. With the RDSR, these systems are able to transfer more technical and geometrical parameters to the patient dose management systems, and can therefore help refine the organ and effective dose calculations.

Compagnone et al. [25] have obtained effective and organ doses for coronary angiographies (CA) and percutaneous coronary interventions (PCI) with a sample of 193 patients deriving conversion factors from KAP and using X-ray systems similar to the ones used in our paper. The authors found an excellent correlation between effective dose and DAP using two different models to calculate organ and effective doses. The results obtained were 0.11 and 0.18 mSv/(Gy.cm^2) for CA and 0.12 to 0.20 mSv/(Gy.cm^2) for PCI for the two models.

Peruzzo-Cornetto et al. [26] have estimated the contribution of interventional cardiology to the population dose in the period 2002–2011, in a representative region of Italy. The authors estimated that interventional cardiology contributed to the ~10% of the total dose by medical ionising radiation examination categories. The conversion factors used to estimate effective doses moved from 0.15 to 0.21 mSv/(Gy.cm^2) depending on the different projections.

Brambilla et al. have recently published a paper reporting conversion factors of effective and equivalent organ doses with the KAP in patients undergoing CA and PCI in a sample of 65 patients [27]. These authors found conversion factor values of 0.30 ± 0.04 mSv/(Gy.cm^2) for CA and 0.33 ± 0.05 mSv/(Gy.cm^2) for PCI. No significant

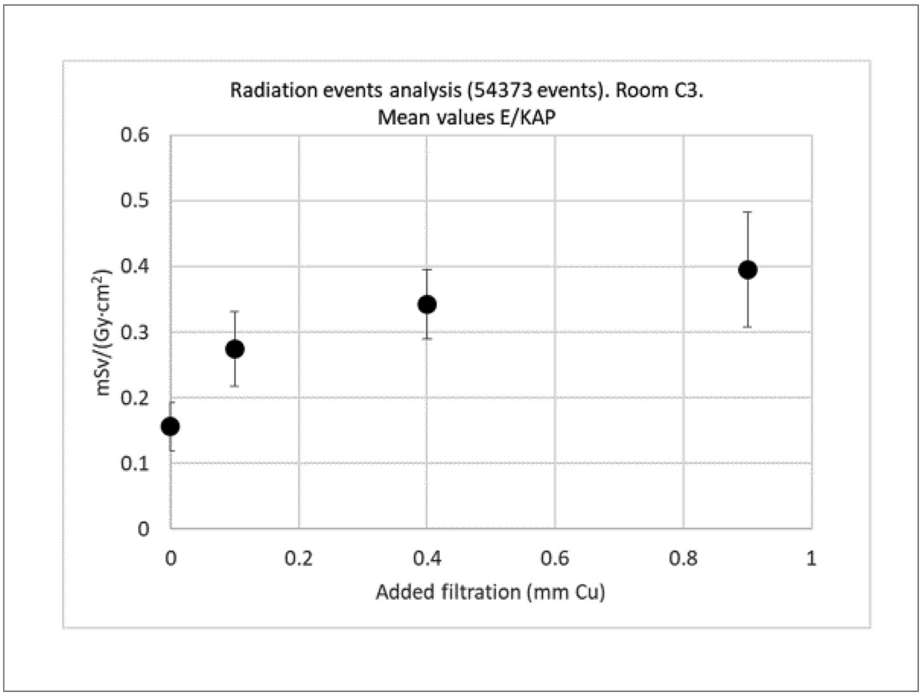

Fig. 5. Conversion factors from KAP to effective dose by added copper filtration. The error bars represent the standard deviation of the sample.

differences were found in the E/KAP between males and females and in patient's weight. The range of conversion factors cited from the literature by Brambilla et al. moved from 0.11 to 0.35 mSv/(Gy.cm^2) for CA and from 0.13 to 0.25 mSv/(Gy.cm^2) for PCI.

Our results, with a much larger sample of procedures, are compatible with the results of Brambilla et al. These authors conclude that a single factor to estimate effective dose could be used for a "specific acquisition protocol" but they also warn that conversion factors might be installation, X-ray beam quality or protocol dependent. In our paper, we have tried to quantify and justify the differences in the conversion factors to help in the evaluation of population doses.

Table 3 presents a summary of the different conversion factors used by UNSCEAR and NCRP and published by several authors with the recommended factors obtained in this paper.

A wide range of factors has been published to estimate effective doses from KAP in interventional cardiology but without a clear indication on the criteria to use the different values when estimating the population (collective) dose.

In our case, the factors were calculated with a large amount of procedures for both, standard systems and the new generation of "patient dose saving systems" using added copper filtration for cine runs. The individual calculation of the effective doses for all the radiation events (using the data transferred by the RDSR) allowed estimating the impact of the added copper filtration in the conversion factors.

Large differences are found in the literature when comparing the factors published to estimate effective doses from KAP. One of the reasons for these differences could be the ICRP organ/tissue weighting factors used by the different authors (from ICRP-103 [4] or ICRP-60 [28]). Notwithstanding, the differences in the estimation of effective doses using both sets of weighting factors are generally not relevant for cardiac procedures and large samples. The European report on "Medical Radiation Exposure of the European Population" [10] indicates that the ratio between the effective doses calculated for coronary angiography, using the weighting factors of ICRP-103 [4] and ICRP-60 [28] is approximately 1.

The variability in the conversion factors published may be mainly due to the use of factors formerly published that neither analysed the impact of the different imaging protocols nor included the percentages of fluoroscopy in cine modes with different added filtrations. The different C-arm angulations, kV values, radiation field size, geometrical factors, etc. also need to be considered. All the above-mentioned technical factors were included in our Monte Carlo calculations for each of the radiation events of the procedures and the information contained in the RDSR was used. When the sample used is large enough, the mean

Table 3
Conversion factors to effective dose from KAP from different authors and sources. Tissue weighting factors from ICRP 103 [4] or ICRP 60 [28].

Author	Ref. and year	Factor min. mSv/(Gy.cm^2)	Factor max. mSv/(Gy.cm^2)	Source and tissue weighting factors
UNSCEAR	[8] 2015	0.12	0.28	Publications, ICRP-60
NCRP	[20] 2009	0.18	0.27	Publications ICRP-60
Betsou	[21] 1998	0.18	0.18	Rando, ICRP-60
Neofotistou	[22] 1998	0.20	0.20	Publications, ICRP-60
Delichas	[23] 2003	0.26	0.27	270 patients, ICRP-60
Bogaert	[24] 2008	0.18	0.21	318 patients, ICRP-60
Compagnone	[25] 2011	0.11	0.20	193 patients, ICRP-60
Peruzzo-Cor	[26] 2016	0.15	0.21	Publications, ICRP-60
Brambilla	[27] 2017	0.30	0.33	65 patients, ICRP-103
This paper		0.21 (no Cu filtration in cine and 0.9 mm in fluoroscopy)	0.29 (0.4 mm Cu filtration in cine and 0.4 mm in fluoroscopy)	925 patients and 75,347 radiation events, ICRP-103

values of the factors obtained is relevant to estimate the contribution of the cardiology procedures to the population dose.

As mentioned in the limitations section, the conversion factors proposed in this paper have been obtained from two specific X-ray systems (with the description of the filtrations and operation modes). Were other X-ray systems with different filtrations to be used, the factors might need to be refined.

In doing our calculations on a large sample of procedures, we have tried to derive practical factors with their standard deviation to estimate collective doses without knowing the particular protocols used (as it is the case in many hospitals and countries). This may be the case during the UNSCEAR surveys or when applying the article 64 (estimates of population doses) of the European Directive 2013/59/EURATOM. For these calculations, it is neither practical nor in general feasible to take into account the individual protocols of the examinations.

Thanks to these factors, patients with complex pathologies may be informed on the relative radiation risks associated with the different imaging procedures (catheterisation, computed tomography and nuclear medicine). The KAP is today available in practically all the X-ray systems used in interventional cardiology, and in many hospitals, the KAP is included in the patient report (or in the hospital PACS –picture archive and communication system- or other central registry).

To have a factor allowing estimating effective dose from the KAP is an easy way to facilitate some kind of rough information on effective dose for comparisons with other imaging procedures or other sources of radiation (e.g. background radiation).

A practical approach suggested to estimate effective doses from KAP for the classical interventional X-ray systems (with cine protocols without Cu filtration) and for the new generation of interventional systems using "patient dose reduction techniques" (with Cu filtration for the cine acquisitions and new methods of image post-processing) may be:

For X-ray systems without Copper filtration in cine

Effective dose (mSv) = KAP (Gy.cm^2) × 0.21

For X-ray systems with "dose reduction techniques" using 0.4 mm of Cu filtration in cine

Effective dose (mSv) = KAP (Gy.cm^2) × 0.29

NOTES: KAP values should be corrected by the local calibration factor and by the attenuation of the table and mattress. The "conversion factors" (0.21 and 0.29) should be refined according to the Copper filtrations used in the local protocols.

5. Limitations

The conversion factors reported in this paper have been obtained from a large number of standard clinical procedures of interventional cardiology performed with two X-rays systems with local settings and local operation protocols. The results obtained with other X-ray systems or with different protocols could need some refinement concerning these factors.

6. Conclusions

The conversion factors we calculated to estimate effective doses from the KAP values supplied by the X-ray systems currently used for interventional radiology, resulted in 0.21 ± 0.05 (using copper filtration for fluoroscopy and no copper filtration for cine) and 0.29 ± 0.03 for the new X-ray systems with patient dose reduction techniques, using copper filtration for cine and fluoroscopy.

The new X-ray systems with patient dose reduction techniques usually use added copper filtration for cine, a factor that needs to be taken into account when estimating effective doses (and population doses) from the KAP.

A reduction in the KAP values arising from the new technologies and from post-processing does not always involve a similar reduction in effective doses if the copper filtration is increased in the X-ray beams. In our case, the global conversion factor increased by 38%, from 0.21 to 0.30 mSv/(Gy·cm2) in comparison to the protocol used in the standard X-ray system without copper filtration for cine acquisitions.

Acknowledgments

This work has been partially founded by the Spanish Ministry of Economy and Competitiveness (Instituto de Salud Carlos III) and European Regional Development Fund (ERDF) under the project MEDICI number PI16/01413 and the Spanish National Safety Council under the project EDOCI.

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

References

[1] International Electrotechnical Commission (IEC). Medical electrical equipment – Part 2–43: Particular requirements for the basic safety and essential performance of X-ray equipment for interventional procedures. IEC 60601-2-43 ed 2.0. (Geneva, Switzerland, 2010).

[2] ICRP-135. Diagnostic Reference Levels in Medical Imaging. ICRP Publication 135. Ann. ICRP 2017; 46(1): 1-143.

[3] Tapiovaara M, Siiskonen T. PCXMC: A Monte Carlo program for calculating patient doses in medical X-ray examinations (2nd ed). Finnish Centre for Radiation and Nuclear Safety, Report STUK-A231. (Helsinki, Finland, 2008). https://www.stuk.fi/palvelut/pcxmc-a-monte-carlo-program-for-calculating-patient-doses-in-medical-x-ray-examinations (last access 11 August 2019).

[4] ICRP-103. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 2007; 37 (2-4): 1-332.

[5] ICRP-105. Radiological protection in medicine. ICRP Publication 105. Ann ICRP 2007;37(6):1–63.

[6] European Council. 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. Off J Eur Union, No. L13, p. 73, 2014.

[7] UNSCEAR 2008 (Annex A). UNSCEAR 2008 Report. Sources and effects of ionizing radiation. UNSCEAR 2008 Report Volume 1. Sources. Annex A. Medical radiation exposures. Accessed on 9 August 2019: https://www.unscear.org/docs/publications/2008/UNSCEAR_2008_Report_Vol.I.pdf.

[8] UNSCEAR Global Survey on Medical Exposure. A User Manual. Draft Version May 2015. Accessed on 9 August 2019: http://www.survey.unscear.org/lib/exe/fetch.php?media=unscear_user_manual_version_may2015.pdf.

[9] Radiation protection N° 154. European guidance on estimating population doses from medical x-ray procedures. European Commission (2008). Directorate-General for Energy and Transport. https://ec.europa.eu/energy/en/radiation-protection-publications (Accessed: 11 August 2019).

[10] Radiation Protection N° 180. Medical Radiation Exposure of the European Population. European Commission. Directorate-General for Energy (2015). https://ec.europa.eu/energy/en/radiation-protection-publications (Accessed: 11 August 2019).

[11] Sánchez Casanueva RM, Vano Carruana E, Fernández Soto JM, Fernández-Ortiz A, Alfonso Manterola F, Goicolea Ruigómez J. Contribution of interventional cardiology to the collective dose in Spain. J Radiol Prot 2018;38(1):N1–7.

[12] Gislason-Lee AJ, Keeble C, Malkin CJ, Egleston D, Bexon J, Kengyelics SM, et al. Impact of latest generation cardiac interventional X-ray equipment on patient image quality and radiation dose for trans-catheter aortic valve implantations. Br J Radiol 2016;89(1067):20160269.

[13] Kastrati M, Langenbrink L, Piatkowski M, Michaelsen J, Reimann D, Hoffmann R. Reducing radiation dose in coronary angiography and angioplasty using image noise reduction technology. Am J Cardiol 2016;118:353–6.

[14] Balter S, Brinkman M, Kalra S, Nazif T, Parikh M, Kirtane AJ, et al. Novel radiation dose reduction fluoroscopic technology facilitates chronic total occlusion percutaneous coronary interventions. Eurointervention 2017;13(e1468):e1474.

[15] Ten JI, Fernandez JM, Vano E. Automatic management system for dose parameters in interventional radiology and cardiology. Radiat Prot Dosimetry 2011;147(1–2):325–8.

[16] 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(1–4):53–6.

[17] Siiskonen T, Ciraj-Bjelac O, Dabin J, Diklic A, Domienik-Andrzejewska J, Farah J, et al. Establishing the European diagnostic reference levels for interventional cardiology. Phys Med 2018;54:42–8.

[18] DeLorenzo MC, Yang K, Li X, Liu B. Comprehensive evaluation of broad-beam transmission of patient supports from three fluoroscopy-guided interventional systems. Med Phys 2018;45(4):1425–32.

[19] Sánchez RM, Vano E, Fernández JM, Escaned J, Goicolea J. Pifarré X. DOCCACI Group. Initial results from a national follow-up program to monitor radiation doses for patients in interventional cardiology. Rev Esp Cardiol (Engl Ed) 2014;67(1):63–5.

[20] National Council on Radiation Protection and Measurements (NCRP). Ionizing Radiation Exposure of the Population of the United States, Report 160, Bethesda, MD; 2009.

[21] Betsou S, Efstathopoulos EP, Katritisis D, Faulkner K, Panayiotakis G. Patient radiation doses during cardiac catheterization procedures. Br J Radiol 1998;71(846):634–9.
[22] Neofotistou V, Karoussou A, Lobotesi H, Hourdakis K. Patient dosimetry during interventional cardiology procedures. Radiat Prot Dosimetry 1998;80(1–3):151–3.
[23] Delichas MG, Psarrakos K, Molyvda-Athanassopoulou E, Giannoglou G, Hatziioannou K, Papanastassiou E. Radiation doses to patients undergoing coronary angiography and percutaneous transluminal coronary angioplasty. Radiat Prot Dosimetry 2003;103(2):149–54.
[24] Bogaert E, Bacher K, Thierens H. A large-scale multicentre study in Belgium of dose area product values and effective doses in interventional cardiology using contemporary X-ray equipment. Radiat Prot Dosimetry 2008;128(3):312–23.
[25] Compagnone G, Ortolani P, Domenichelli S, Ovi V, Califano G, Dall'Ara G, et al. Effective and equivalent organ doses in patients undergoing coronary angiography and percutaneous coronary intervention. Med Phys 2011;38(4):2168–75.
[26] Peruzzo Cornetto A, Aimonetto S, Pisano F, Giudice M, Sicuro M, Meloni T, et al. The contribution of interventional cardiology procedures to the population radiation dose in a 'health-care level I' representative region. Radiat Prot Dosimetry 2016;168(2):261–70.
[27] Brambilla M, Cannillo B, Matheoud R, Compagnone G, Rognoni A, Bongo AS, et al. Conversion factors of effective and equivalent organ doses with the air kerma area product in patients undergoing coronary angiography and percutaneous coronary interventions. Phys Med 2017;42:189–96.
[28] ICRP-60. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann. ICRP 1991; 21 (1-3): 1-201.