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The Information System on Occupational Exposure in Medicine, Industry and Research (ISEMIR): Interventional Cardiology

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THE INFORMATION SYSTEM ON OCCUPATIONAL EXPOSURE IN MEDICINE, INDUSTRY AND RESEARCH (ISEMIR): INTERVENTIONAL CARDIOLOGY

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THE INFORMATION SYSTEM ON OCCUPATIONAL EXPOSURE IN MEDICINE, INDUSTRY AND RESEARCH (ISEMIR): INTERVENTIONAL CARDIOLOGY

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

In the last three decades, the use of image guided interventional procedures in cardiology has increased significantly, bringing great benefit to millions of patients around the world. As technology improves, the medical capabilities of these procedures continue to expand, adding further to the armamentarium for diagnosis and treatment of patients with cardiac problems. All of these procedures require health professionals (including interventional cardiologists, electrophysiologists, nurses and medical radiation technologists) to be present in the room and alongside the patient when radiation is being used, which may result in occupational exposure.

While it has been long known that there is significant potential for health professionals in attendance during interventional cardiology to receive non-trivial occupational exposures, reported details have been typically limited to a few specific interventional cardiology facilities and situations. A more global perspective has been lacking, as is the availability of a systematic means for improving occupational radiation protection in interventional cardiology facilities throughout the world.

In 2006, the IAEA published the Fundamental Safety Principles (IAEA Safety Standards Series No. SF-1), which sets out the fundamental safety objective and principles of protection and safety. In 2011, the IAEA published Radiation Protection and Safety of Sources: International Basic Safety Standards (IAEA Safety Standards Series No. GSR Part 3 (Interim Edition)), which sets out the requirements for meeting the fundamental safety objective and applying the principles specified in the Fundamental Safety Principles. The establishment of safety requirements and provision of guidance on occupational radiation protection is a major component of the support for radiation protection and safety provided by the IAEA to Member States.

This publication was developed under the IAEA's statutory responsibility to facilitate worldwide application of safety standards for the protection of people against exposure to ionizing radiation. The publication details the results of the Information System on Occupational Exposure in Medicine, Industry and Research (ISEMIR) (2009–2012) and, in particular, the activities of the Working Group on Interventional Cardiology that culminated in the development of the ISEMIR international database for interventional cardiology (ISEMIR-IC). The ISEMIR project arose from the Occupational Radiation Protection International Action Plan (approved by the IAEA Board of Governors September in 2003), which identified the need for networks to be established to enable interested parties to exchange information, experiences and lessons learned.

The IAEA acknowledges the significant work carried out by the members of the WGIC. The IAEA also acknowledges the many individuals, IC facilities and regulatory bodies that participated in the surveys; without this input, the project would not have progressed. The IAEA officer responsible for this publication was J.C. Le Heron of the Division of Radiation, Transport and Waste Safety.

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1. INTRODUCTION

1.1. BACKGROUND TO ISEMIR

The International Atomic Energy Agency (IAEA) initiated in early 2009 the Information System on Occupational Exposure in Medicine, Industry and Research, referred to as the ISEMIR project.

The catalyst for the ISEMIR project was the experience of the Information System on Occupational Exposure (ISOE) of nuclear power plant operators around the world, where having a database that contained detailed information on operational occupational doses across many nuclear power plants enabled the comparison and benchmarking of doses for specific occupations, functions and tasks [1]. This in turn enabled the assessment of the impact of various radiation protection actions. As the ISOE database became populated with data covering many years, dose trends were also able to be analysed. If such an approach was successful for nuclear power plant workers, perhaps a similar approach could be utilized in the non-nuclear domain – i.e. medicine, industry and research.

The ISEMIR project was overseen by an Advisory Group, whose first task was to identify a limited number of specific areas of radiation use in medicine, industry and research where non-trivial occupational exposures occur, and which might benefit from such an approach as described above.

The Advisory Group of ISEMIR identified two such areas of radiation use, namely interventional cardiology (IC) and industrial radiography (IR), and two separate working groups were formed to address these areas. This TECDOC will discuss only IC. A companion TECDOC covers IR.

1.2. WORKING GROUP ON INTERVENTIONAL CARDIOLOGY

The Working Group on Interventional Cardiology (WGIC) met for the first time in February 2009. The mandate for WGIC was to gain a world-wide overview of occupational exposures and radiation protection of staff in IC; to identify both good practices and shortcomings, and hence define actions to be implemented for assisting each of regulatory bodies, medical physicists, medical staff, technicians and nurses, dosimetry service providers and X ray machine suppliers, in improving occupational radiation protection; to propose recommendations for harmonising monitoring procedures; and to set up a system for regularly collecting and analysing occupational doses for individuals in IC and for dissemination of this information to improve occupational radiation protection.

This TECDOC presents the main activities of the WGIC and the results. Additional information is also available at the WGIC webpages: http://www-ns.iaea.org/tech-areas/communication-networks/norp/isemir-wgic.htm

2. WORLDWIDE SURVEY OF OCCUPATIONAL RADIATION PROTECTION IN INTERVENTIONAL CARDIOLOGY

2.1. INTRODUCTION

One of the first actions of the WGIC was to devise three questionnaires to gain insight into occupational radiation protection in IC around the world. Three questionnaires were sent out: one to chief interventional cardiologists, another to individual interventional cardiologists and a third to the national or state radiation protection regulatory body. The cardiologist questionnaires were designed to be easy and quick to answer, with questions on the use of personal dosimeters, use of protection equipment, training in radiation protection, and knowledge of doses. The regulatory body questionnaire addressed occupational exposure data for IC personnel, as well as requirements for radiation protection training. The following sections provide full details on the survey. Various aspects of the survey have also been presented at several conferences and meetings, and selected results published in the literature [2].

2.2. METHOD

To gain an overview of the current worldwide status of radiation protection practice in IC, three questionnaires were sent to individual interventional cardiologists, chief interventional cardiologists and radiation protection regulatory bodies. The interventional cardiologist questionnaires were designed to be easy and quick to answer, with questions on the use of personal dosimeters, use of protection equipment, training in radiation protection, and knowledge of doses. The regulatory body questionnaire addressed occupational exposure data for IC personnel, as well as requirements for radiation protection training and the wearing of personal dosimeters. The questions from the questionnaires are listed in Appendix I, Section I.4.

Contact was made with interventional cardiologists by each of the members of the WGIC, thus giving representation from most regions of the world — Asia-Pacific, Europe, Latin America and North America. This was primarily through the members' professional associations, including attendance at conferences or workshops and through work and professional connections.

Contact with the national regulatory bodies was made by email by the Scientific Secretary of the WGIC. Some Member States have a federal system of government, where each 'state' within the country has jurisdiction over the use of X rays. In these cases, each 'state' regulatory body was contacted. The initial email inviting participation in the survey contained two attachments — a letter describing the ISEMIR project, and the regulatory body questionnaire itself. In cases where there was uncertainty in the appropriateness of the initial contact person or even the organization, the recipient of the email was asked to forward the email to a more appropriate person, with a copy to the Scientific Secretary. Follow-up emails were sent about 6 weeks later to those regulatory bodies that had not responded at that time. Almost all responses were sent to the IAEA by email.

2.3. RESULTS

2.3.1. Caveats

Because of the nature of the distribution of the interventional cardiologist questionnaires, it is recognised that the results cannot purport to be truly representative of the worldwide practice of IC and all results must be interpreted with this caveat. For the interventional cardiologists, contact was made through professional meetings, personal contact, or through established research connections. The interventional cardiologist responses are a convenience sample, and give anecdotal evidence of current practice. Further, some of the questions involved a cardiologist assessing his/her own habits or performance, and hence are subject to distortions of perception versus reality.

The distribution of the regulatory body questionnaire was systematic – contact was attempted for all IAEA Member States. However not all regulatory bodies responded, and many of those not responding were regulatory bodies of large countries. Further, of those that did respond many had no specific data on occupational exposure of persons working in IC.

Notwithstanding the above caveats, some useful insight into current radiation protection practice in IC was gained, as summarized below. Further details are given in Appendix I.

2.3.2. Number of responses

The responses were as follows:

Interventional cardiologists:

— 45 responses from chief interventional cardiologists of IC facilities, from 24 countries;

— 201 responses from individual interventional cardiologists from 32 countries.

Regulatory bodies:

— 81 responses from regulatory bodies (56 national regulatory bodies and 25 state regulatory bodies) from 57 countries[1]. Contact was attempted with 191 radiation protection regulatory bodies from 136 countries, giving a participation rate of about 40%. The responding regulatory bodies have jurisdiction over countries whose summed population is about one-quarter of the world's total population.

2.3.3. IC X ray systems

— 87% of responding IC facilities reported that their X rays systems were less than 10 year old.

[1] Some Member States have a federal system of government, where each 'state' within the country has jurisdiction over the use of X rays.

— IC facilities from developed[2] countries tended to have newer equipment compared with those in developing countries – 56% and 18%, respectively, for equipment less than 5 years old.

— Developing countries tended to have older systems than those in developed countries (82% of systems are more than 5 years old). Note however that there are relatively few data from developing countries.

2.3.4. IC facilities, procedures and personnel

From the responses from the 45 IC facilities:

— There was an average of about two IC laboratories per IC facility;

— There was an average of just under 2000 procedures performed per year per IC facility globally, ranging from an average of 1200 per IC facility in Africa and Latin America to nearly 3000 in North America;

— Almost 900 procedures were performed per laboratory per year, globally;

— There was an average of 11 monitored professionals per laboratory, among whom 4 were physicians (38%), 4 were nurses (37%) and 3 were other professionals (25%);

— There was an average of about 1 nurse per interventional cardiologist across all regions;

— There was an average of just over 200 procedures performed per interventional cardiologist per laboratory per year, globally.

From the responses from the 201 interventional cardiologists:

— An interventional cardiologist performs an average of 382±293 procedures per year; approximately 90% of interventional cardiologists perform fewer than 600 procedures per year;

— Individual cardiologists have an average of 14±8 years of experience, fairly uniformly distributed from 1 to 30 years. IC seems to be a growing profession with a steady inflow of new interventional cardiologists;

— The IC procedures were divided into, on average, approximately two-thirds diagnostic and one-third interventional procedures.

Reconciling the numbers of procedures per laboratory per year with the number of procedures performed by an interventional cardiologist would suggest that either many interventional cardiologists are working in more than one IC laboratory or facility and/or many procedures involve more than one interventional cardiologist.

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[2] Countries were classified as “developed” if they are a Health-care Level I country as defined by UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) otherwise they were classified as “developing”.

2.3.5. Interventional cardiologists' stated personal monitoring habits

— 76% of interventional cardiologists stated that they always use their personal dosimeter (77% in developed countries and 70% in developing countries);

— 45% of interventional cardiologists stated that they always use two dosimeters (50% in developed countries and 24% in developing countries).

Even as self-reported, the use of dosimeters is less than the desired full compliance. It is recognized that the use of two dosimeters in developing countries may not be an available option due to limited dosimetry resources.

2.3.6. Interventional cardiologists' stated radiation protection habits

— 97% of interventional cardiologists stated that they always wear a protective apron (97% in developed countries, 97% in developing countries);

— 43% of interventional cardiologists stated that they always wear protective eyewear (47% in developed countries, 24% in developing countries);

— 78% of interventional cardiologists stated that they always use a ceiling screen (82% in developed countries, 59% in developing countries);

— 77% of interventional cardiologists stated that they always use a table screen (80% in developed countries, 62% in developing countries);

— From these results, it can be deduced that 37% of interventional cardiologists claim to always use all protective tools – apron, eyewear, ceiling screen and table curtain (40% in developed countries, and 24% in developing countries).

The relatively low percentage of interventional cardiologists using protective eyewear needs to be considered in the context of the use of ceiling suspended screens, as the latter can also afford protection to the eyes. Of those interventional cardiologists who said they never used protective eye wear (68), 51 (75%) said that they always used a ceiling suspended screen, and of those who said they sometimes used protective eye wear (47), 26 (55%) said that they always used a ceiling suspended screen. As reported, 81% of interventional cardiologists always use either protective eyewear or a ceiling suspended screen or both, and only 6% stated that they never used protective eyewear and never used a ceiling suspended screen. The need to always use some form of protection for the lens of the eye is likely to gain even more importance in the light of new data from exposed human populations suggesting that lens opacities occur at doses far lower than those previously believed to cause cataracts.

The non-availability of particular protective devices clearly has an impact on radiation protection practice in IC, but in many cases it appears that the interventional cardiologist is electing to not use available protective devices. This is reflected in the data on the relationship between use of protective devices and radiation protection training (see also Section 2.3.8).

It is likely that the participants in this study were 'better than average' interventional cardiologists — they were either attending a conference/workshop or had contact with the medical physics profession. As a result of this probable selection bias in the sample and the self-reporting bias mentioned earlier, the results of this study are probably more indicative of the upper end of current good radiation protection habits in IC.

2.3.7. Interventional cardiologists' knowledge of doses

— 64% of interventional cardiologists stated that they know their own personal doses (66% in developed countries, 57% in developing countries);

— 43% of interventional cardiologists stated that they know their patients' doses (45% in developed countries, 32% in developing countries);

— 38% of interventional cardiologists stated that they know both their own and their patients' doses (41% in developed countries, 22% in developing countries);

— Some cardiologists, while not knowing this information, specified that they have access to it.

As noted above, the interventional cardiologists in the survey are likely to be better informed than many of their colleagues, so these results are probably more indicative of the upper end of interventional cardiologists' knowledge of doses.

2.3.8. Interventional cardiologists' training and certification in radiation protection

— 83% of interventional cardiologists stated that they had undergone radiation protection training (84% in developed countries, 78% in developing countries);

— 52% of interventional cardiologists stated that they had received certification in radiation protection (54% in developed countries, 41% in developing countries);

— 20% of interventional cardiologists stated that they have neither undergone training nor received certification (13% in developed countries, 34% in developing countries).

It is likely that these results over-estimate the prevalence of radiation protection training in IC, due to the aforementioned likelihood of interventional cardiologists in the survey having had professional contact with medical physicists, and hence radiation protection training.

Having radiation protection training and certification improves interventional cardiologists' self-reported radiation protection behaviour in IC, as follows:

— Always wears their dosimeter: 88% if they have certification in radiation protection, and 56% if no radiation protection training;

— Always wears two dosimeters: 57% if they have certification in radiation protection, and 26% if no radiation protection training;

— Always wears an apron: 100% if they have certification in radiation protection, and 85% if no radiation protection training;

— Always wears eye protection: 46% if they have certification in radiation protection, and 41% if no radiation protection training;

— Always uses a ceiling screen: 79% if they have certification in radiation protection, and 71% if no radiation protection training;

— Always uses a table screen: 79% if they have certification in radiation protection, and 59% if no radiation protection training.

The importance of radiation protection training in ensuring good radiation protection practice in IC cannot be over emphasized.

2.3.9. Regulatory body requirements for wearing dosimeters

About 60% of regulatory bodies (45 out of 79) stated that they specify the number and position of dosimeters for the monitoring of staff in IC. Of these:

— 40% specify the use of one dosimeter, to be worn above the apron in most cases (~80%);

— 20% specify the use of two dosimeters, one above and one below the apron;

— The other 40% did not provide details.

2.3.10. Regulatory body requirements for radiation protection training in IC

51% of regulatory bodies (41 out of 80) stated that personnel must have radiation protection training in order to be able to perform IC procedures.

2.3.11. Regulatory body requirements for licensing or certification in radiation protection

There was a spectrum of (radiation protection) licensing systems in use throughout the world, ranging from the interventional cardiology physician not needing to have a licence to use radiation in interventional cardiology to a mandatory requirement for such a licence.

The question on licensing or certification requirements for persons to be able to perform fluoroscopy in interventional cardiology unfortunately yielded ambiguous results. Analysis of responses and accompanying comments indicated that there was confusion about who needed to be licensed (e.g. the physician or the radiographer), what the licence was for (e.g. use of radiation or practice of medicine), and who issued the licence (e.g. radiation protection regulatory body or medical registration body or similar). No meaningful results could be determined, except as given above.

2.3.12. Availability of IC occupational exposure data from the regulatory bodies

— More than 60% of the responding regulatory bodies (52 of 81) were not able to provide occupational dose data that were useful for the purposes of this survey, either because dose data were not available or the data were not appropriate.

— Reasons for the non-availability of dose data included either that there was no central dose register or, if there were, it was not readily accessible by the regulatory body. Typically, personal monitoring was being performed by a 3rd party technical service organization, and the regulatory body was notified of doses only when ‘needed’, such as when a given value was exceeded.

— Data were available, but were not useful for the purposes of this survey because:

- There was no specific classification for IC and the reported data were 'contaminated' with doses from other occupational classes and functions, such as interventional radiology;

- Corrected and uncorrected doses were mixed – e.g. doses were corrected for wearing position only if they exceeded some threshold and these corrected values were entered back into the original database of raw doses;

- The database contained only doses above some action level, and hence were not the full distribution;

- The presence of 'administrative doses', doses typically assigned to replace unknown doses when dosimeters are not returned for reading, distorted the dose distribution.

— 25 regulatory bodies had data on the numbers of workers being monitored in IC for each of physicians and other professionals. Summing these data showed that IC physicians represented slightly more than one-third of the IC staff being monitored (700 of 1907).

2.3.13. Reported occupational dose data for personnel in IC

— Data from 29 countries were considered suitable and were included in the dose analysis.

— For those regulatory bodies reporting data for IC physicians as a group, in 2008 the mean country median effective dose was 0.73±0.62 mSv per year, and the mean country 3rd quartile effective dose was 1.09±0.69 mSv per year. The 2008 results are based on reported monitoring results from 23 countries, for a total of 1432 interventional cardiology physicians. Data were analysed on a per country basis.

— For 2006 and 2007, the mean country median effective doses for IC physicians were 0.67±0.64 and 0.78±0.60 mSv/year respectively, and the mean country 3rd quartile effective doses were 1.80±2.54 and 1.35±1.25 mSv/year respectively.

— For those regulatory bodies reporting data for other professionals in IC as a group, in 2008 the mean country median effective dose was 0.76±0.68 mSv per year, and the mean country 3rd quartile effective dose was 1.10±1.09 mSv per year. The 2008 results are based on reported monitoring results from 17 countries, for a total of 825 other professionals working in IC. Data were analysed on a per country basis.

— For 2006 and 2007, the mean country median effective doses for other professionals were 0.42±0.38 and 1.07±1.17 mSv per year respectively, and the mean country 3rd quartile effective doses were 1.28±1.06 and 1.46±1.12 mSv per year respectively.

— For those regulatory bodies reporting data only for all persons in IC combined, in 2008 the mean country median effective dose was 0.56±0.47 mSv per year, and the mean country 3rd quartile effective dose was 1.68±0.21 mSv per year. The 2008 results are based on reported monitoring results from only 4 countries, for a total of 391 persons working in IC. Data were analysed on a per country basis.

— For 2006 and 2007, the mean country median effective doses for all persons in IC combined were 0.59±0.34 and 0.76±0.39 mSv per year respectively.

The similarity in the values of doses reported for the IC physicians as a group and for the other professionals as a group is perhaps worth commenting on. Emphasis has traditionally been placed on the IC physician as being the person with the most potential for being occupationally exposed. Radiation protection training promotes the use of additional radiation protection tools, such as the ceiling suspended screen, to bring about a lower level of occupational exposure for the physician. The other professionals, such as the nurse, may not be afforded the same access to these additional radiation protection tools, and must rely on a protective apron and distance as the main means of protection. If this is so, attention may need to be given to providing additional protective tools for these other professionals if occupational radiation protection in IC is to be truly optimized.

Despite some vetting of the dose data provided, other issues remain. Often personnel who have moved into more administrative duties remain on the monitored list, thus lowering average doses for that occupational group in the facility. It is very difficult to keep track of the doses for interventional cardiologists who may work in more than one facility, and reported doses may not be total doses across all workplaces. The treatment of doses at the limit of detection may differ — a zero dose may be assigned, or a nominal minimum reporting dose or even some other nominal value. This may affect the statistical analysis, especially the mean.

The largest potential shortcoming of the reported results is whether the interventional cardiologists were actually wearing dosimeters whenever they were performing IC procedures. The reported annual median dose values were lower than would have been expected based on validated data from facility-specific studies, indicating that compliance with continuous individual monitoring is often not being achieved in IC. Reasons for non-compliance range from simple negligence to deliberate avoidance because of the fear of exceeding some dose threshold that then leads to regulatory investigation (often as a result of an above-the-apron dose value being used as a surrogate for effective dose with no correction). All of these reasons would indicate that the results reported above are likely to be an under-estimate of the real situation.

2.4. DISCUSSION

2.4.1. Implications of the survey for the on-going objectives of the WGIC under the ISEMIR project

As described in Section 1.2, one of the objectives of the WGIC was to set up a system for regularly collecting and analysing occupational doses for individuals in IC and for dissemination of this information to improve occupational radiation protection. The experience gained in conducting this survey had implications for achieving this objective. The response to the survey was reasonably good, with a total of 327 responses from 73 countries — a reasonably sized sample from a wide range of countries. However, as already discussed in section 2.3.1, there were shortcomings, particularly with respect to sampling, bias, and obtaining valid or meaningful dose records.

In particular:

— Obtaining a truly representative world-wide sample of interventional cardiologists requires different strategies from those used in the survey;

— The possibility of personal bias in reporting radiation protection habits needs to be minimized;

— Gaining access to detailed occupational exposure records for interventional cardiologists requires different strategies from those used in the survey;

— The impact on dose assessment of non-compliance in the wearing of dosimeters needs to be assessed, or at least minimized.

The WGIC, at its second meeting in October 2009, discussed these issues and decided to trial a methodology based on a direct approach to specific IC facilities (see Section 3). The personnel dose data collection needed to impose as little additional work as possible — it should be essentially the same annual dose summary and analysis that an IC facility should be performing as part of its quality management of occupational radiation protection. Such a quality management system facilitates easy tracking of occupational exposures for individuals, allows comparisons between personnel performing similar numbers of procedures and functions, and most importantly enables the medical physicist, radiation protection officer or other expert to provide specific advice on radiation protection to persons whose dose results indicate that their current radiation protection practice is not as good as it could be.

2.5. CONCLUSIONS FOR THE 2009 SURVEY

The three questionnaires of the 2009 survey provided insight into the then current status of occupational radiation protection in IC facilities around the world. The nature of the distribution of the interventional cardiologists' questionnaires and the potential for bias when persons completing a questionnaire are being asked to evaluate their own habits and knowledge, place limitations on the representativeness of the results.

Notwithstanding these caveats, the results of the interventional cardiologists' questionnaires indicated that there was room for significant improvement in the practice of occupational radiation protection in IC throughout the world. Individual monitoring dosimeters were not being worn all the time, protective clothing and tools were not being used all the time, knowledge of personal and patient doses was still limited, and radiation protection training and certification of IC personnel were not yet universal. The last point was particularly important as the survey results provide further evidence that radiation protection training improves the practice of radiation protection in IC.

Obtaining reliable data on occupational exposures in IC from radiation protection regulatory bodies proved to be difficult. Many regulatory bodies have limited access to such data and, even if they do have access, the data are often not detailed enough to provide the required information for particular roles and functions within the IC facility. A further complicating factor is that recorded doses may underestimate the true occupational exposure because compliance of IC personnel with continuous monitoring can be poor, and because an individual's exposures from different IC facilities may not be summed. Alternative strategies

for the collection of IC occupational dose data would need to be utilized if a worldwide database of such information were to be established under the ISEMIR project.

3. PILOT SURVEY ON OBTAINING OCCUPATIONAL EXPOSURE DATA IN INTERVENTIONAL CARDIOLOGY

3.1. INTRODUCTION

There were several conclusions from the 2009 survey, as discussed in Section 2. In particular, there was room for significant improvement in the practice of occupational radiation protection throughout the world, and obtaining reliable data on occupational exposures in IC from radiation protection regulatory bodies was difficult. Many regulatory bodies have limited access to such data and, further, the limited data that were available were not detailed enough to facilitate analysis of occupational exposure within IC facilities. Detailed information on occupational doses in a given IC facility and the circumstances under which the doses were incurred needs to be known if the next step of implementing actions to improve the optimization of occupational radiation protection is to take place.

On the basis of these conclusions, alternative strategies for the collection of reliable IC occupational dose data needed to be considered. This resulted in a pilot survey in the period 2010-11 to test the feasibility of obtaining IC occupational dose data directly from IC facilities and to test whether the reported data could be used to derive dose metrics for occupational exposure in IC.

Section 3 presents and discusses the results of this pilot survey. Various aspects of the survey have also been presented at several conferences and meetings.

3.2. METHOD

Over the period 2010-11 a multinational pilot survey collected data at the hospital or facility level, on individual personnel doses and workloads. Excel data sheets were designed and sent to IC facilities to facilitate the collection of IC occupational dose data. For each individual, the information collected included their role (interventional cardiologist, electrophysiologist, nurse, technician, or other), their status (staff or trainee), the number of procedures per year, their annual occupational dose data, and their occupational dose data per monitoring period. The dose quantities requested were $H_p(10)$ measured over the apron, $H_p(10)$ measured under the apron, lens dose and hand dose, as appropriate to a given IC facility.

Initial contact with selected IC facilities was made by the members of the WGIC, primarily by email, explaining the purpose of the pilot survey and inviting participation. Many of the contacted IC facilities had previously participated in the 2009 survey. Approximately 100 IC facilities around the world were contacted in this manner, resulting in responses from 26 IC facilities and about 850 IC personnel including interventional cardiologists, electrophysiologists, nurses and technicians.

The data were used to derive estimates of occupational dose per IC procedure — namely, over-apron $H_p(10)$ per procedure, under-apron $H_p(10)$ per procedure, occupational effective dose per procedure, lens dose per procedure, and hand dose per procedure. Changes in these dose metrics could then be used to assess the effectiveness of any subsequent actions to improve occupational radiation protection.

3.3. RESULTS

The purpose of the pilot survey was to test the feasibility of first obtaining occupational dose data directly from IC facilities and, second, of deriving dose metrics for occupational exposure in IC that could, in a later situation, be used to assess the effectiveness of actions to improve the optimization of occupational radiation protection in a given IC facility.

To that end, the scope of the pilot survey was quite limited, with contact being made with only selected IC facilities. The values that are reported below are valid in their context, but do not purport to be necessarily representative of the worldwide practice of IC.

The summarized results of the pilot survey are presented here, with detailed results given in Appendix II. Note that the term 'technician' is used in many tables and figures to mean technicians, technologists, radiographers and similar occupations; and the abbreviation EP means electrophysiology. While the abbreviation IC means interventional cardiology, in the interest of brevity, it is intended to include both interventional cardiology and electrophysiology. Hence the terms 'IC facility' 'IC personnel' and 'IC' physicians are wider in scope than just specifically 'interventional cardiology'. When referring to a particular cardiology subspecialty, the terms interventional cardiologist and electrophysiologist are used.

3.3.1. Number of responses

— There were 26 responses from IC facilities, from 16 countries.

— Data for individual IC personnel were obtained from:

- 347 interventional cardiologists, 49 electrophysiologists, and 18 'other' physicians;
- 210 nurses, 126 technicians, and 102 persons that were either a nurse or technician.

See Tables 25-27 and Figures 12-13 in Appendix II for more details.

3.3.2. Number of procedures per year

– Statistics on the reported number of procedures per year performed by personnel in a given IC facility are summarized in Table 1. See Tables 28-29 and Figures 14-15 in Appendix II for more details.

TABLE 1. NUMBER OF PROCEDURES PERFORMED BY IC PERSONNEL PER YEAR IN A GIVEN FACILITY[1]

	Number of responses	Mean	Minimum	Median	Maximum
Interventional cardiologists	258	248	1	177	1394
Electrophysiologists	45	189	43	182	496
Interventional cardiologists, qualified	149	321	10	277	1394
Interventional cardiologists, trainee	43	181	1	162	674
Nurses	47	317	2	250	667
Technicians	41	448	73	484	1025

[1] Some personnel may work in other facilities as well, but this was not relevant to this survey as it is the dose-workload relationship in a given facility that is of importance for a given person.

3.3.3. Monitoring periods and numbers of dosimeters worn

— 60% (15 out of 26) of responding IC facilities had monthly monitoring periods, 20% (5 out of 26) had three-monthly monitoring periods and 15% (4 out of 26) had two-monthly monitoring periods. Two IC facilities did not provide monitoring period data.

— Numbers of dosimeters worn were:

- Two dosimeters (over-apron and under-apron) were worn by physicians in 27% (7 out of 26) of IC facilities and by non-physician personnel in 15% (4 out of 26) of facilities;
- One over-apron dosimeter was worn by physicians in 19% (5 out of 26) of IC facilities and by non-physician personnel in 23% (6 out of 26) of facilities;
- One under-apron dosimeter was worn by physicians in 50% (13 out of 26) of IC facilities and by non-physician personnel in 38% (10 out of 26) of facilities;
- Numbers of dosimeters worn were not known for physicians in one IC facility and for non-physician personnel in 6 facilities.
- Extremity dosimeters were worn by physicians in 19% (5 out of 26) of IC facilities and lens dosimeters in only one facility.

See Tables 30-31 in Appendix II for more details.

3.3.4. Quality of the dose data reported

— From a total of 2026 monitoring periods reported, 84% (1691 out of 2026) had a numerical value (zero or greater). For the remaining 16%, no dose data were provided.

— From a total of 1648 monitoring periods reported with an under-apron dosimeter, 92% (1509 out of 1648) had a numerical value (zero or greater). 55% (824 out of 1648) were reported with a zero value.

— From a total of 888 monitoring periods reported with an over-apron dosimeter, 70% (625 out of 888) had a numerical value (zero or greater). 33% (206 out of 888) were reported with a zero value.

— Averaged per physician:

- 82% of monitoring periods in the year had a reported numerical value (zero or greater); but 6% of physicians (16 out of 251) had no monitoring periods with a reported numerical value (zero or greater).
- 77% of reported over-apron doses in the year were not zero; but 11% of physicians (10 out of 95) had all monitoring periods with a reported value equal to zero.
- 53% of reported under-apron doses in the year were not zero; but 23% of physicians (48 out of 207) had all monitoring periods with a reported value equal to zero.

See Tables 32-35 and Figures 16-17 in Appendix II for more details.

3.3.5. Estimates of dose metrics – occupational doses per procedure

Reported zero doses were included in the estimation of dose metrics.

— Over-apron dose[3] per procedure (μSv/procedure):

- All interventional cardiologists (135): mean = 39.7 ± 13.8; range 0 - 700; median = 24.4;
- All electrophysiologists (27): mean = 34.7 ± 11.7; range 0 - 102; median = 28.6;
- Qualified interventional cardiologists (94): mean = 30.3 ± 5.9; range 0 - 150; median = 26.8;
- Trainee interventional cardiologists (41): mean = 61.1 ± 43.1; range 0 - 700; median = 21.1;
- Nurses (20): mean = 9.9 ± 5.5; range 0 - 32; median = 1.5;
- Technicians (31): mean = 7.2 ± 2.1; range 0 - 25; median = 7.0.

— Under-apron dose[4] per procedure (μSv/procedure):

- All interventional cardiologists (113): mean = 11.4 ± 5.6; range 0 - 230; median = 2.6;

[3] Over apron dose means the reported $H_p(10)$ from a dosimeter placed above the protective apron, normally at collar level.
[4] Under apron dose means the reported $H_p(10)$ from a dosimeter placed under the protective apron, normally at chest or waist level.

- All electrophysiologists (20): mean = 1.1 ± 0.7; range 0 - 6; median = 0.3;
- Qualified interventional cardiologists (92): mean = 10.8 ± 5.1; range 0 - 159; median = 2.8;
- Trainee interventional cardiologists (21): mean = 61.1 ± 43.1; range 0 - 700; median = 21.1;
- Nurses (36): mean = 0.3 ± 0.2; range 0 - 4; median = 0.1;
- Technicians (13): mean = 0.6 ± 0.3; range 0 - 1.5; median = 0.2.

— Occupational effective dose[5] per procedure (μSv/procedure):

- All interventional cardiologists (255): mean = 10.6 ± 4.5; range 0 - 419; median = 2.3;
- All electrophysiologists (45): mean = 3.0 ± 1.0; range 0 - 18; median = 2.0;
- Qualified interventional cardiologists (148): mean = 12.5 ± 5.2; range 0 - 261; median = 3.1;
- Trainee interventional cardiologists (41): mean = 16.3 ± 20.5; range 0 - 419; median = 2.7;
- Nurses(46): mean = 0.7 ± 0.4; range 0 - 7; median = 0.2;
- Technicians (41): mean = 0.7 ± 0.2; range 0 - 3; median = 0.5.

— Lens dose[6,7] per procedure (μSv/procedure):

- All interventional cardiologists (201): mean = 31.7 ± 9.9; range 0 - 700; median = 16.1;
- All electrophysiologists (37): mean = 44.8 ± 36.5; range 0 - 680; median = 19.2;
- Qualified interventional cardiologists (94): mean = 30.3 ± 5.8; range 0 - 149; median = 25.9;
- Trainee interventional cardiologists (41): mean = 61.1 ± 43.1; range 0 - 700; median = 21.1;

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[5] Effective dose has been calculated from the reported dosimeter values using the algorithm: If 2 dosimeters, ED = 0.075OA + 1.64UA; if one dosimeter, ED = 0.075OA or ED = 1.64UA, depending on which dosimeter was worn, where ED = effective dose, OA = reported $H_p(10)$ from a dosimeter placed over the protective apron, and UA = reported $H_p(10)$ from a dosimeter placed under the protective apron. See also reference [2].

[6] Lens dose means the reported value from a dosimeter specifically placed to measure lens dose or the reported over apron dose.

[7] Note that over apron doses do not, and lens dose may not, account for the possibility that protective eyewear was being used.

- Nurses (20): mean = 9.9 ± 5.5; range 0 - 32; median = 1.5;
- Technicians (31): mean = 7.2 ± 2.1; range 0 - 25; median = 7.0.

— Hand dose per procedure (μSv/procedure):

- All interventional cardiologists (17): mean = 199.5 ± 114.5; range 6 - 724; median = 56.9.

See Tables 36-46 in Appendix II for more details.

3.3.6. Filtering the raw data to improve its quality

Seven quality factors, as presented in Table 2, were used to assess and filter the raw dose data.

TABLE 2. QUALITY FACTORS USED TO ASSESS THE RAW REPORTED DOSE DATA AND THE DERIVED DOSE DATA

Quality Factor	Based on:
QF1	Percentage of monitoring periods with a reported numerical value, including zero and 'less than minimum detectable or reported dose'[1].
QF2	Percentage of reported over-apron numerical values that were NOT zero.
QF3	Percentage of reported under-apron numerical values that were NOT zero.
QF4	Coefficient of variation of reported over-apron values.
QF5	Coefficient of variation of reported under-apron values.
QF6	Percentage of calculated effective dose values that were NOT 'zero'.
QF7	Coefficient of variation of calculated effective dose values.

[1] Over-apron results were used if available, otherwise under-apron or deep dose results were used.

As can be seen from Table 2, the quality factors fall into 3 groups – the first, QF1, assesses the compliance of an individual in being monitored, with the caveat that it is possible for the dosimeter to be routinely returned but having never been used for its intended purpose in the cardiac investigation suite; the second group, QF2, QF3, QF6, assesses the percentage of reported 'zero doses' for an individual; and the third group, QF4, QF5, QF7, assesses consistency of reported doses for an individual. By assigning a threshold value to a quality factor, suspect data can be excluded from the analysis. The influence of such filtering on deriving estimates of the dose metrics for qualified interventional cardiologists is presented in detail in Appendix II (see Tables 47-55 and Figures 18-23), summarized here and illustrated in Table 3 and Figure 1.

— The application of any filter reduced the number of data in the analysis;

— The application of any filter increased the value of the dose metric relative to that derived from the raw data, primarily due to the removal of varying numbers of 'zero doses';

— Having data for all monitoring periods (QF1 = 100) was clearly important in obtaining a robust estimate for the dose metric;

— The presence or not of 'zero doses' (QF2, QF3, QF6) impacted on the value of the dose metric;

— The use of the coefficient of variation quality factor (QF4, QF5, QF7) as a filter affected the dose metric in a similar manner to that of excluding zero doses.

TABLE 3. INFLUENCE ON THE ESTIMATES OF THE EFFECTIVE DOSE METRIC (OCCUPATIONAL EFFECTIVE DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS TO FILTER THE RAW DATA (SEE TABLE 2)

Quality filter applied	**Effective dose per procedure (μSv/proc)**		**Number of data**
	Mean	**2 x standard error**	
No filter – raw data	14.8	6.3	117
QF1 > 75	17.9	7.6	95
QF1 = 100	20.8	9.1	78
QF6 > 50	15.6	6.9	104
QF6 > 75	16.7	7.8	91
QF6 = 100	21.9	10.8	64
QF7 < 150	17.9	8.2	86
QF7 < 100	15.4	7.3	62
QF7 < 50	18.6	11.5	32
QF1 = 100 & QF6 = 100	27.2	13.5	50
QF1 = 100 & QF7 < 100	18.9	9.0	49
QF1 = 100 & QF6 = 100 & QF7 < 100	21.6	11.1	39

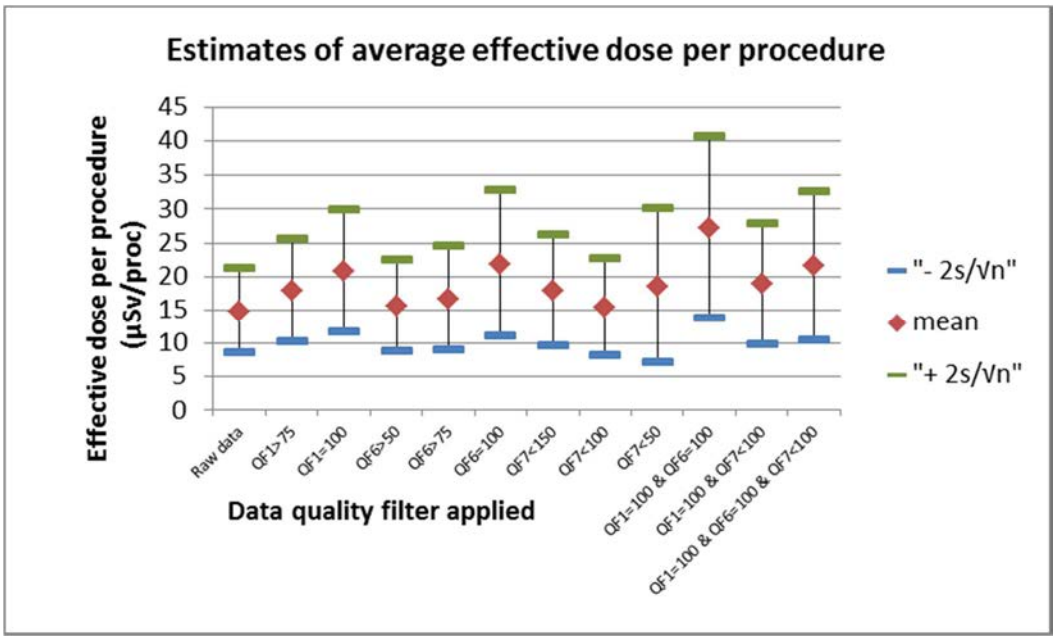

FIG. 1. Estimates of occupational effective dose per procedure (mean ± 2 × standard error) for qualified interventional cardiologists as a function of the data quality filter applied.

3.3.7. Using the dose metric to benchmark IC facilities

Although the number of IC facilities was small and the number of participating IC personnel in each facility relatively small, the average dose metric of effective dose per procedure was derived for each IC facility for the largest occupational group in the survey – namely qualified interventional cardiologists. The detailed results are given in Appendix II (Table 56). Using the raw data, the facility-averaged dose metric (occupational effective dose per procedure) for qualified interventional cardiologists ranged from 0.9 to 75.8 µSv per procedure, with a mean and median of 9.6 and 3.9 µSv per procedure. This would seem to be indicative of the wide variation in radiation protection practice between the different IC facilities and, further, points to how a larger set of data with more participating facilities and personnel could provide a very useful benchmarking tool as an aid to improving the optimization of occupational radiation protection.

3.3.8. Using the dose metric to identify potential areas for action

In a similar way, the dose metric for a given group of persons can be used to identify areas that could be improved or, on the other hand, that represent good practice. To illustrate, the qualified interventional cardiologists in the survey were divided into two groups – those who performed fewer than 150 procedures in the reported year and those who performed 150 or more procedures in the year. The estimates of mean effective dose per procedure were 37.0 ± 21.5 and 6.8 ± 1.9 µSv per procedure for the lower workload group and higher workload group, respectively, indicating that some particular attention probably needs to be given those interventional cardiologists who perform fewer procedures. These results are presented in Figure 2 and further details are given in Appendix II, Table 57.

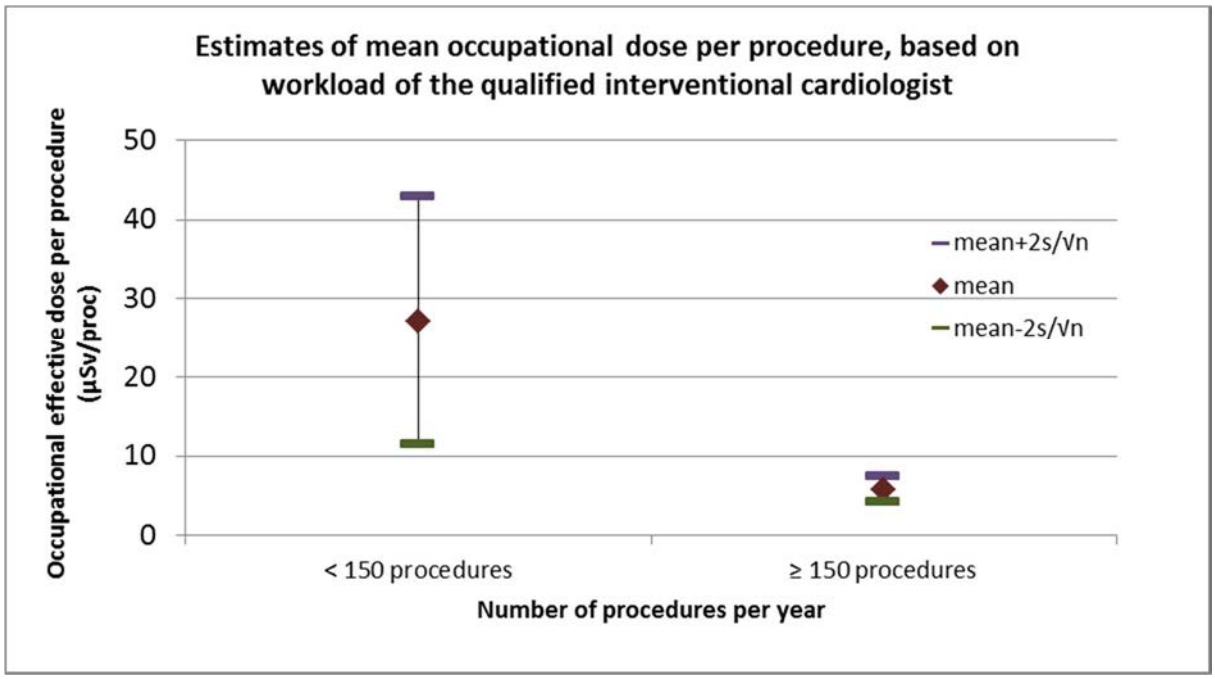

FIG. 2. Example of statistical analysis, comparing the performance of qualified interventional cardiologists with a lower workload with those having a higher workload, thus identifying an area needing attention.

3.4. DISCUSSION

3.4.1. Obtaining occupational exposure data from IC facilities

One of the reasons for the pilot survey was to ascertain whether it was realistic to obtain occupational exposure data for IC personnel directly from the IC facilities where they worked. Of those IC facilities initially contacted, about one-quarter provided actual occupational exposure data for their facility. On the one hand this would indicate that data can be obtained directly from facilities — a significant proportion was willing to participate in a pilot survey, with no particular added value for doing so. But on the other it emphasizes that, if the proposed ISEMIR international database (see Section 4) is to be successful, there needs to be a clear incentive for participation — in particular it needs to be demonstrable that the database would be a tool for each IC facility to use as an interactive means for improving occupational radiation protection for their workers.

3.4.2. Facility specific dose data

IC is characterized in many countries throughout the world by personnel who work in more than one IC facility. This can cause substantial problems in determining compliance with occupational dose limits. For this pilot survey, annual occupational doses were not reported — it was not known whether the participating personnel worked elsewhere and, further, this information was not necessary for the purposes of this survey.

The goal of the pilot survey is to assess whether IC facility specific data could be used to improve the practice of occupational radiation protection in that facility. If, for example, an interventional cardiologist worked in two IC facilities, then the circumstances of his or her

occupational exposure are likely to be quite different in each facility — the types of X ray equipment used and their performance characteristics, the protective tools available, the types of procedures being performed, and the room layout, to name a few factors, are likely to be different. Therefore, for the example interventional cardiologist, optimization of occupational protection would need to take place independently in each of the facilities, by looking at the factors relevant to that facility. In the ISEMIR international database (see Section 4), the example interventional cardiologist would "appear" in the database in two places, assuming both of the IC facilities were participating.

3.4.3. Monitoring periods and numbers of dosimeters worn

The majority of participating IC facilities had a monthly monitoring period. In one of these cases there were actually only 11 'months' in the year, with January being combined with February. Similarly, some of the 'two-monthly' or 'three-monthly' monitoring periods were not uniform — holiday seasons typically were the reason why the cycles were not always evenly spaced. Such irregularities in monitoring periods need to be able to be accommodated in the design of the data entry for the ISEMIR international database (see Section 4).

Two dosimeters were worn in a minority of the participating IC facilities. The International Commission on Radiological Protection have for some time recommended that two dosimeters be worn in IC [3], [4], but the responses from the survey show that the single under-apron dosimeter remains the most common form of monitoring. This tension between legal requirements in many countries and what is best practice does have implications for the quality of the occupational dose data as will be discussed further, below.

3.4.4. Quality of reported dose data

The interpretation of the monitoring period dose data, as initially provided, was not always straight forward. In many instances (16% of reported monitoring periods) there were gaps or blanks in the data and it was unclear whether these were due to no dose value being reported because either the person concerned was away and did not use a dosimeter or the dosimeter was lost, or the dosimeter was carried over to the next monitoring cycle, or for some other reason.

Another problem area was the minimum detectable dose or the minimum reported dose. Each dosimetry provider has their own minimum detectable dose and, in addition, there are various ways of reporting the minimum dose. These include reporting it as 'less than the minimum dose' or assigning a zero dose, or assigning the minimum detectable dose, or assigning some fraction of the minimum detectable dose, such as one-half or one-fifth.

For a viable ISEMIR international database (Section 4), it is crucial that the reported occupational dose data for any given IC facility are entered into the database in a consistent manner. The database data entry screens need to provide clear guidance on what is required.

The percentage of reported zero doses was quite significant – for physicians with dose data per monitoring period, 55% for the under-apron dosimeters and 33% for the over-apron dosimeters. Further, for the 108 physicians who used over-apron dosimeters, 17 had a reported annual dose of zero, and of these 11 were for physicians who performed more than 100 procedures in the year. A reported zero dose for a dosimeter can be due to very good radiation protection practice but, unfortunately, it can also be due to the dosimeter not being worn in the investigation suite. The over-apron results, at least, point to the latter interpretation, with poor compliance in being monitored being a real issue that could

undermine the usefulness of the ISEMIR international database (Section 4). Perhaps the future availability of the ISEMIR international database will provide an additional incentive for on-going compliance in wearing dosimeters.

Zero doses for under-apron dosimeters are a more likely eventuality, especially if good radiation protection practice is being followed. Therefore from a dose metric perspective, and for determining whether dosimeters are being worn, under-apron dosimeters are not as useful as over-apron dosimeters – for under-apron dosimeters, the magnitude of the reported dose will always be smaller and nearer the minimum detectable dose, making the signal to noise ratio poor. As mentioned above, while legal requirements in some countries may necessitate the use of under-apron dosimeters, the more prevalent use of over-apron dosimeters or double dosimetry would help the implementation of the ISEMIR international database.

3.4.5. Quality of reported workload data

The IC facilities also provided estimates of the annual number of procedures performed by each of the IC personnel. The nature of the numbers reported indicated that in some cases the values reported were rounded estimates (such as 300 or 350), while in other cases there had clearly been efforts to more accurately assess the number. However in any case, it is recognized that not all procedures are equal. Some of the procedures may have been only diagnostic in nature, while others were interventional. Two facilities gave additional data on both numbers and types of procedures, giving an average of 2.8 diagnostic procedures per interventional procedure (range 0 to 6) for the 23 interventional cardiologists in the two facilities. In some facilities a diagnostic procedure that then continued to become an interventional procedure may have been counted as a single procedure while in other facilities it may have been counted as two. Of course, not all procedures are of equal complexity. Complexity affects patient doses and therefore affects staff doses. All of these considerations affect the robustness of using the naïve 'number of procedures' as the denominator of the dose metric. In developing the ISEMIR international database (Section 4), more detailed information on the type of workload will be sought.

Further, an interventional cardiologist may have performed 300 procedures, but his or her role may not have always been that of the primary operator. Again, additional information on the person's role in a procedure and the technique being used (femoral versus radial artery entry for interventional cardiology; thoracic (pacemaker) versus femoral access for electrophysiology) would increase the potential usefulness of derived dose metrics in the ISEMIR international database.

3.4.6. Estimates of dose metrics — occupational doses per procedure

This was the second main purpose of the pilot survey — to test the feasibility of deriving dose metrics in IC, where the dose metrics would be used to assess the impact of various actions to improve the optimization of occupational radiation protection.

Dose metrics were derived for over-apron doses, under-apron doses, effective doses, lens doses and hand doses per procedure. One would expect *a priori* that the estimate for a given metric (i.e. mean ± 2 × the standard error) would be relatively large, given the large number of factors that can affect the occupational dose a person receives during a given procedure. This was certainly borne out in the results presented in this report. Notwithstanding the large variations, the derived occupational effective doses per procedure for interventional cardiologists and for electrophysiologists were broadly consistent with the values reported in

a review article for diagnostic catheterizations (0.02–38.0 μSv) and interventions (0.17–31.2 μSv), and ablations (0.24–9.6 μSv) and pacemaker or intracardiac defibrillator implantations (0.29–17.4 μSv), respectively [5].

As one includes or excludes the conditions that affect occupational exposure, one would expect the estimate for a given metric to converge to a representative value (for those conditions), and for the standard error to become narrower as the attributes become more selective. The dose metric for a given 'profile' of circumstances then becomes a tool for investigating performance of occupational radiation protection practice.

Many of the reported data were of poor quality. The results of using derived quality factors to filter the raw data in an attempt to improve the data have been presented in the results section, and show a fairly mixed outcome. A further indicator of whether the use of quality factors for filtering the data was useful was to consider the effect on the coefficient of correlation between the annual dose and the annual workload. For the over-apron doses for qualified interventional cardiologists, the application of various quality factor filters improved the value of the correlation coefficient from 0.75 (for the raw data) to as high as 0.88. For the under-apron doses and effective doses, there was no correlation between doses and workload, and the application of filters made no improvement. This latter result again illustrates the limitations of under-apron doses (and hence derived effective doses) in the role of dose metrics due to their low signal to noise ratios.

For this pilot survey, a simplistic approach was taken for calculating effective dose. The algorithm reported by Clerinx et al [6] for two dosimeters, effective dose = 0.075 × over-apron dose + 1.64 × under-apron dose, was used where data for two dosimeters were given. Where only an over-apron dosimeter value was reported, the algorithm was simplified to effective dose = 0.075 × over-apron dose; where only an under-apron dosimeter value was reported, the algorithm was simplified to effective dose = 1.64 × under-apron dose. It is recognized that this introduces a systematic underestimate for both the single dosimeter situations. Data were available from four IC facilities that enabled calculation of over-apron dose to under-apron dose ratios. The data presented in Appendix II (Tables 45 — 46) point to there being a difference between the mean ratios for interventional cardiologists and for electrophysiologists. More robust algorithms for calculating effective dose, depending on whether under-apron, over-apron or both dosimeters are being worn, need to be decided upon for use in the ISEMIR international database.

Although not an aim of this pilot survey, it is worth commenting that the derived dose metrics for the lens of the eye for the various professional roles, as presented in Section 3.3.5, coupled with the annual workloads reported in Section 3.3.2 would indicate the possibility of exceeding the annual dose limit of 20 mSv for the lens of the eye [7], [8]. From the reported data, approximately 8% (22 out of 268) of the interventional cardiologists and electrophysiologists would have exceeded the dose limit, based on over-apron and lens dosimeters and without making any allowance for whether protective eyewear may have been worn. Such results would further emphasize the clear need for optimization of occupational radiation protection in interventional cardiology.

3.4.7. The next step — the ISEMIR international database

The results and experiences of the two WGIC surveys have led to the design and development of the ISEMIR international database (see Section 4). The purpose of the ISEMIR database will not be to assess compliance with occupational dose limits, but rather will be to provide an

active tool for assessing the level of, and hence guiding, implementation of the radiation protection principle of optimization of protection at a given IC facility. Once fully developed and populated, the database will support three broad types of analyses — occupational doses per procedure as a function of personnel and facility attributes; benchmarking; and trends with time. Indicative illustrations of the first two types of analyses have been presented in the results section.

3.5. CONCLUSIONS OF THE PILOT SURVEY

The second survey has shown that it is feasible to obtain data on occupational exposure in IC directly from IC facilities. The participation rate was about 25% which indicates that, if the proposed ISEMIR international database is to be successful, there needs to be a clear incentive for participation — in particular it needs to be demonstrable that the database can be used by an IC facility as an interactive tool for improving their occupational radiation protection.

Many of the data from the IC facilities were of poor quality, with significant numbers of reported zero doses or missing data. Compliance with monitoring continues to be an issue with IC personnel. Clarity of instructions to IC facilities re future data submissions to the ISEMIR international database will be crucial.

Dose metrics (occupational dose per procedure) could be derived from the survey data. For physicians, the mean occupational effective dose per procedure was about 10 μSv for interventional cardiologists, and about 3 μSv for electrophysiologists. The dose metric for trainee interventional cardiologists appeared to be higher than for qualified interventional cardiologists. Both nurses and technicians had a mean occupational effective dose per procedure of about 1 μSv.

Derived quality factors, based on analyses of personnel dose data per monitoring period, were used to filter the raw data in an attempt to improve the dose metric estimates. This was most successful for analyses based on over apron dosimeters, highlighting the limited usefulness of under apron dosimeters when the detected dose is close to the limits of detectability.

The two WGIC surveys have set the stage for the ISEMIR international database that will facilitate the calculation of a given dose metric for a selected set of circumstances for occupational exposure. The ISEMIR database will be an active tool for assessing the level of, and hence guiding, implementation of the radiation protection principle of optimization of protection at a given IC facility. Once fully developed and populated, the database will support three broad types of analyses — occupational doses per procedure as a function of personnel and facility attributes; benchmarking; and trends with time.

4. THE INTERNATIONAL DATABASE – ISEMIR-IC

4.1. INTRODUCTION

A carefully designed database can be an effective tool for the implementation of optimization of occupational radiation protection. One of the original longer term aims of the ISEMIR project was to utilize such an approach. In the context of IC, there was a need to explore the feasibility of setting up a system for the regular collection and analysis of occupational doses for individuals in IC, and for the use of this information to improve occupational radiation protection.

As described in Section 2, the 2009 survey had shown that obtaining reliable data on occupational exposures in IC from radiation protection regulatory bodies, the traditional source, was difficult and, further, that the limited data available were not detailed enough to facilitate analysis of occupational exposure in terms of role, function, radiation protection practice, and other parameters within the IC facility. Alternative means for the collection of IC occupational dose data were then considered, resulting in a pilot survey in 2010-11 that tested the feasibility of obtaining such information directly from IC facilities. This is described in Section 3.

The 2010-11 pilot survey, Section 3, showed that data could be obtained directly from IC facilities, but that the quality of the data varied considerably. Nevertheless, the data collected were able to demonstrate the clear need worldwide for improved optimization of occupational radiation protection in IC. The data collected also provided confirmation that, with sufficient data, analyses could be performed comparing doses for specific occupational roles and conditions, assessing the impact of radiation protection actions, and for following dose trends.

These experiences underlined the need for an international database for specific occupational groups, with appropriate analysis functionality. This has led to the design and development of the ISEMIR international database. The purpose of the ISEMIR database is not to assess compliance with occupational dose limits, but rather to be an active tool for assessing the level of, and hence guiding, implementation of the radiation protection principle of optimization of protection at a given IC facility.

4.2. DATABASE STRUCTURE

The ISEMIR international database is being developed to provide a web-based tool to help end-users improve their implementation of optimization in occupational radiation protection in particular targeted areas. The ISEMIR database will have a section dedicated to IC, described in more detail below.

The database is structured around individual IC facilities. In designing the database it was important to avoid collecting unnecessary data but, at the same time, to ensure that there would be sufficient resolution to allow useful analysis and hence provide the information to then help improve the implementation of optimization in occupational radiation protection. In other words, the database has to contain as much information about the factors that could influence the occupational dose of an individual person in IC as possible, without tipping the balance to make participation in the database an unattractive time consuming burden. As a result, some fields in the database will be mandatory and others will be optional.

Each participating IC facility will provide a facility profile, including the annual number of procedures performed, number of catheterization laboratories, the X ray equipment used, typical patient doses for given procedures, X ray equipment performance data (dose rates), and data on the personal dosimetry provider.

Each IC facility will also provide information on individual personnel working in the facility, including their occupational doses, profession, role, workload, radiation protection training, X ray equipment used, and radiation protection habits (use of protective clothing and tools). Data will be entered for a calendar year, with an additional option of data per monitoring period for occupational doses and workloads. Dose data can be entered as one or more of the following personal equivalent doses: under-apron $H_p(10)$, over-apron $H_p(10)$, over-apron $H_p(0.07)$, extremity $H_p(0.07)$; and lens $H_p(3)$. Occupational doses will then be calculated, including effective dose, doses to the lens of the eyes and hand doses, as applicable.

Individuals and facilities will be anonymised in the database. IC personnel who work in more than one facility, will have their doses and other information entered separately and independently by each participating facility, as the implementation of optimization and how it affects the individual may well be quite different in each facility.

There must be a means for assessing the effectiveness of the optimization of protection in an IC facility. The metric will be the occupational dose per procedure. Statistics on the distribution of dose metrics can then be determined for any combination of the aforementioned personnel attributes and facility attributes – profession, role, workload, radiation protection training, X ray equipment used, radiation protection habits, X ray equipment dose rates, typical patient doses, and the implementation of a quality assurance programme. This is illustrated in Figure 3.

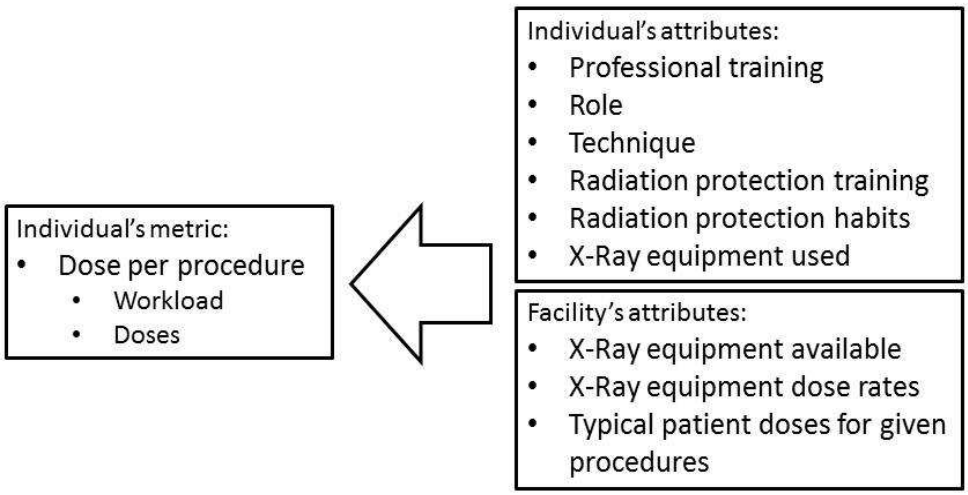

FIG. 3. The performance of any individual can be assessed by deriving statistics on the distribution of dose metric as a function of one or more of the individual attributes and the facility's attributes.

4.3. DATA QUALITY

One of the issues identified in the pilot survey (Section 3) was the poor quality of much of the submitted data. The reasons included: dose values of 'zero' above the apron for personnel performing significant numbers of procedures; missing data for some monitoring periods; and inconsistent data — significant inconsistencies across monitoring periods, and under-apron doses exceeding over-apron doses. Therefore the ability to filter the submitted raw data on the basis of 'quality' will be provided.

Raw data will remain as part of the database, but a registered database user can exclude poor quality data from their analyses if they so choose, using pre-defined quality filters. These filters utilize quality factors that assess dose reporting completeness, dose value consistency, and the prevalence of reported zero doses. The use of such quality filters has been described and discussed in Section 3.3.6 and Appendix II.4 and II.8.

4.4. ANALYSIS AND REPORTING

Once populated, the database will support three broad types of analyses — occupational doses per procedure as a function of personnel and facility attributes; benchmarking; and trends with time.

4.4.1. Statistical analysis

Statistical analysis on the dose metrics for a given group of persons can be used to identify areas that could be improved or, on the other hand, that represent good practice.

A registered IC facility user will be able to perform statistical analyses of occupational effective dose per procedure, eye dose per procedure and hand dose per procedure, based on combinations (one or more) of the individuals' personal attributes and facility attributes. In particular, this will include estimates of expected 'population' means for these combinations of attributes.

This can be illustrated using data from the 2010-11 survey, as is been reported in Section 3.3.8 and illustrated in Figure 2. Consultant interventional cardiologists were divided into two groups based on the number of procedures they performed in the reported year — the first group performed fewer than 150 procedures; the second group performed at least 150 procedures. The estimates of mean effective dose per procedure were 37.0 ± 21.5 and 6.8 ± 1.9 μSv per procedure for the lower workload group and higher workload group, respectively — a difference that was statistically significant ($p=0.0002$, by t-test). Such analysis draws attention to those interventional cardiologists who perform relatively low numbers of procedures, and the need to identify means for improving their radiation protection.

More complex analyses will be possible. For example, the mean effective dose per procedure could be derived for those interventional cardiologists who use always wear a lead apron and always use a protective suspended screen, evaluating those who always use femoral artery access and those who use femoral artery access for less than 50% of cases. Another example might be comparing two groups of electrophysiologists with the same personal attributes, where one group uses X ray equipment with a mean fluoroscopy dose rate less than 20 mGy per minute for a 20 cm PMMA phantom, while the other uses X ray equipment whose typical

dose rate is greater than 30 mGy per minute. Such analyses could be performed globally (i.e. across all the applicable data in the database) or be restricted to particular regions of the world.

4.4.2. Benchmarking

IC facilities will be able to benchmark their own facility and individual personnel performances against global or regional data and identify areas for improvement and corrective actions that should lead to an improvement in radiation protection. This can occur by benchmarking an IC facility or an individual for the IC facility.

For example, the IC facility's performance could be benchmarked against all other IC facilities — i.e. the data are analysed on a 'per facility' basis, giving distributions of facility — based statistics, such as facility mean effective dose per procedure for qualified cardiologists, thus giving the basis for benchmarking. Alternatively, the occupational effective or lens dose per procedure for an individual from the facility could be compared with the distribution of individuals in the database, selected on the basis of combinations of individuals' attributes that match the individual being bench-marked, again with the option of regional specificity. Other analyses will also be possible.

4.4.3. Trends in time

Analyses of doses per procedure over successive years will be able to be displayed as a function of time. These analyses will be able to be modified as needed by the IC facility user.

4.5. ISEMIR-IC — THE LAUNCH

The ISEMIR-IC database is being developed in stages, as resources permit:

- Stage 1. Data entry on doses, workload, radiation protection training and radiation protection practice for IC personnel in an IC facility;
- Stage 2. Statistical analysis, benchmarking and reporting tools, and improved data entry.

Stage 1 was completed at the end of June 2013, while development of Stage 2 is anticipated to commence in 2014.

4.5.1. Registration and gaining access

The ISEMIR-IC database is based around individual IC facilities. Each IC facility has a point of contact — the Facility Coordinator (FC) — and this person is responsible for that facility's data. The FC and their IC facility must be registered.

Registration to become a FC for an IC facility is via the IAEA Nucleus webpage at: http://nucleus.iaea.org/isemir

After completing the registration page you will be sent an email containing a link to activate your IAEA Nucleus account. Once activated, you are able to sign into Nucleus. Return to http://nucleus.iaea.org/isemir and sign in using your newly created user name and password.

If you are already registered with Nucleus, simply sign in using your existing user name and password.

After sign in, you are taken to the Home page of ISEMIR-IC. On this page you need to click on the button ‘Request Access’ to gain entry to the database.

Detailed information on using Stage 1 of ISEMIR-IC is given in a User’s Guide available at http://www-ns.iaea.org/tech-areas/communication-networks/norp/documents/isemir-ic-user-guide.pdf .

The success of the ISEMIR-IC international database depends strongly on the participation of sufficient numbers of IC facilities and hence all IC facilities around the world are encouraged to register and participate.

5. OTHER ACTIVITIES OF THE WGIC

5.1. RECOMMENDATIONS FOR OCCUPATIONAL RADIATION PROTECTION IN INTERVENTIONAL CARDIOLOGY

The WGIC developed guidelines to help promote occupational radiation protection in interventional cardiology. To improve the outreach of such guidelines, relevant regional professional societies were approached resulting in a set of recommendations that were endorsed by Asia Pacific Society of Interventional Cardiology (APSIC), the European Association of Percutaneous Cardiovascular Interventions (EAPCI), the Latin American Society of Interventional Cardiology (SOLACI), and the Society for Cardiovascular Angiography and Interventions (SCAI). The recommendations were published as both a full set of recommendations and a summary set of recommendations by the journal of SCAI, namely Catheterization and Cardiovascular Interventions (CCI) [9], [10]. A version in Spanish is to be published by the Colombian Journal of Cardiology.

5.2. RECOMMENDATIONS ON OCCUPATIONAL DOSES TO THE LENS OF THE EYE IN INTERVENTIONAL CARDIOLOGY

The ICRP published in April 2011 a statement that for the lens of the eye the threshold for tissue reactions is now considered to be 0.5 Gy [7]. As a result ICRP recommended a new occupational dose limit for the lens of the eye of 20 mSv in a year. This recommendation was incorporated into the interim version of the International Basic Safety Standards of the IAEA, published Nov 2011 [8]. Therefore at its meeting in March 2012, the WGIC developed recommendations on occupational doses to the lens of the eye in IC.

The recommendations are presented in Appendix III, and also available on the ISEMIR webpages at:

http://www-ns.iaea.org/tech-areas/communication-networks/norp/documents/recommendations-doses-eye-lens.pdf .

5.3. OPERATOR DOSE STRUCTURED REPORT

The WGIC discussed over the course of its meetings the desirability of having information available for the estimation of occupational dose to IC personnel without having to necessarily rely on personnel wearing their personal dosimeters.

To this end, the WGIC submitted an initial proposal to the Digital Imaging and Communications in Medicine (DICOM) Working Group 02 (Projection Radiography and Angiography) and thence to Working Group 28 (Physics) for a new DICOM standard for an operator dose structured report (ODSR). It is recognized that the relationship between the dose to a fixed point on or near the C-arm and the occupational dose to any particular personnel is very complex, but it was considered that the proposal had merit for further consideration.

At the time of the publication of this TECDOC, discussions on the proposal were still taking place.

5.4. RADIATION PROTECTION POSTER

The WGIC also contributed to the development of the IAEA's Radiation Protection of Patients Unit's poster on simple steps to take for occupational radiation protection in fluoroscopy. The poster, known as '10 Pearls: Radiation protection of staff in fluoroscopy' is available for free download from the RPoP website at:
https://rpop.iaea.org/RPOP/RPoP/Content/AdditionalResources/Posters/fluoroscopy-posters.htm

At the time of the TECDOC's publication the poster was available in 20 different languages.

6. CONCLUSIONS

The activities of the WGIC of the ISEMIR project allow the following conclusions:

The three questionnaires of the 2009 survey provided insight into the then current status of occupational radiation protection in IC facilities around the world. The results of the interventional cardiologists' questionnaires indicated that there was room for significant improvement in the practice of occupational radiation protection in IC throughout the world. Individual monitoring dosimeters were not being worn all the time, protective clothing and tools were not being used all the time, knowledge of personal and patient doses was still limited, and radiation protection training and certification of IC personnel were not yet universal. The last point was particularly important as the survey results provide further evidence that radiation protection training improves the practice of radiation protection in IC.

Obtaining reliable data on occupational exposures in IC from radiation protection regulatory bodies proved to be difficult. Many regulatory bodies have limited access to such data and, even if they do have access, the data are often not detailed enough to provide the required information for particular roles and functions within the IC facility.

Reported doses may underestimate the true occupational exposure because compliance of IC personnel with continuous monitoring can be poor.

The second survey has shown that it is feasible to obtain data on occupational exposure in IC directly from IC facilities. The participation rate was about 25% which indicates that, if the proposed ISEMIR international database is to be successful, there needs to be a clear incentive for participation — in particular it needs to be demonstrable that the database can be used by an IC facility as an interactive tool for improving their occupational radiation protection.

Many of the data from the IC facilities were of poor quality, with significant numbers of missing data or reported zero doses. Compliance with monitoring continues to be an issue with IC personnel.

Dose metrics (occupational dose per procedure) was able to be derived from the survey data. For physicians, the mean occupational effective dose per procedure was about 10 μSv for interventional cardiologists, and about 3 μSv for electrophysiologists. The dose metric for trainee interventional cardiologists appeared to be higher than for qualified interventional cardiologists. Both nurses and technicians had a mean occupational effective dose per procedure of about 1 μSv.

Derived quality factors, based on analyses of personnel dose data per monitoring period, were used to filter the raw data in an attempt to improve the dose metric estimates. This was most successful for analyses based on over apron dosimeters, highlighting the limited usefulness of under apron dosimeters when the detected dose is close to the limits of detectability. A need for more widespread use of double dosimetry would be indicated and a mandatory basis for this would help.

The two WGIC surveys set the stage for the development of the ISEMIR-IC international database that will facilitate the calculation of a given dose metric for a selected set of circumstances for occupational exposure. The ISEMIR-IC database will be an active tool for assessing the level of, and hence guiding, implementation of the radiation protection principle of optimization of protection at a given IC facility. Once fully developed and populated, the

database will support three broad types of analyses — occupational doses per procedure as a function of personnel and facility attributes; benchmarking; and trends with time.

The success of the ISEMIR-IC international database depends strongly on the participation of sufficient numbers of IC facilities and hence all IC facilities around the world are encouraged to register and participate.

The WGIC have developed recommendations on occupational radiation protection in IC that have been endorsed by relevant regional professional societies, and these have been published in the interventional cardiology literature.

The WGIC have also developed recommendations on occupational radiation protection in IC with respect to the lens of the eyes, including that: training in radiation protection must include methods for reducing the dose to the lens of the eye; specific protective tools for the eyes must be used; and IC personnel must be monitored using a protocol that allows the assessment of doses to the lens of the eye.

APPENDIX I. DETAILED RESULTS OF THE 2009 WORLDWIDE SURVEY

I.1. RESULTS FROM THE QUESTIONNAIRE TO CHIEF INTERVENTIONAL CARDIOLOGISTS

The principal findings from the chief interventional cardiologists' questionnaire are given in Section 2.3 of the main document. This section gives additional data in the form of tables.

I.1.1. Responses to the questionnaire

TABLE 4. DETAILS ON IC FACILITIES PARTICIPATING IN THE SURVEY

Region	Number of countries	Number of IC facilities
Africa	1	1
Asia Pacific	7	10
Europe	6	14
Latin America	8	16
North America	2	4
Global	**24**	**45**

I.1.2. Age distribution of the most used X ray system in the IC facilities

TABLE 5. AGE DISTRIBUTION OF THE MOST USED X RAY SYSTEM IN EACH IC FACILITY, BY REGION AND DEVELOPMENT

Region	No. of IC facilities	Number of most used IC X ray systems whose age in years is:		
		<5	5-10	>10
Africa	1	0	1	0
Asia Pacific	10	4	5	1
Europe	14	10	4	0
Latin America	16	4	8	4
North America	4	4	0	0
Global	**45**	**21**	**18**	**6**
Developing MS[a]	11	2	5	4
Developed MS	34	19	13	2

[a] MS means Member States.

I.1.3. Numbers of laboratories, procedures and personnel in interventional cardiology

TABLE 6. FACILITIES, LABORATORIES AND PERSONNEL IN INTERVENTIONAL CARDIOLOGY

	Global	Africa	Asia Pacific	Europe	Latin America	North America
Laboratories per IC facility	**2**	2	2	2	2	4
No. of total professionals per Laboratory (Lab)	**11**	10	15	10	8	11
No. of IC physicians per Lab	**4.0**	5.5	5.1	3.7	3.2	4.1
No. of nurses per Lab	**3.9**	3.0	5.3	3.7	2.6	4.5
Procedures per IC facility per year	**1973**	1195	2268	2466	1205	2893
Procedures per Lab per year	**868**	598	986	1145	643	681
Procedures per IC physician per Lab per year	**216**	109	194	297	203	165
No. of physicians monitored per total no. of monitored professionals	**0.38**[a]	**0.55**	**0.34**	**0.40**	**0.40**	**0.38**
No. of nurses monitored per total no. of monitored professionals	**0.37**	0.30	0.35	0.40	0.33	0.41
No. of other professionals monitored per total no. of monitored professionals	**0.25**	0.15	0.31	0.20	0.27	0.21
No. of nurses monitored per monitored IC physician	**1.0**	0.5	1.0	1.0	0.8	1.1
No. of other professionals monitored per monitored IC physician	**0.7**	0.3	0.9	0.5	0.7	0.6

[a] The average of 0.4 IC physicians per total professionals is in agreement with the results obtained from analysis of the questionnaires addressed to regulatory bodies about the number of IC physicians monitored per total number of monitored workers in IC.

I.2. RESULTS FROM THE QUESTIONNAIRE TO INDIVIDUAL INTERVENTIONAL CARDIOLOGISTS

The principal findings from the individual interventional cardiologists' questionnaire are given in Section 2.3 of the main document. This section gives additional data in the form of tables and figures. Not all questions were answered by all responders.

I.2.1. Responses to the questionnaire

TABLE 7. NUMBER OF INDIVIDUAL INTERVENTIONAL CARDIOLOGISTS THAT RESPONDED

Region	No. of countries	No. of interventional cardiologists
Africa	2	3
Asia Pacific	13	62
Europe	6	56
Latin America	9	35
North America	2	45
Global	**32**	**201**

I.2.2. Years of experience of surveyed interventional cardiologists

TABLE 8. YEARS OF EXPERIENCE OF INDIVIDUAL INTERVENTIONAL CARDIOLOGISTS SURVEYED

Region	No. of countries	No. of interventional cardiologists	Average experience (years)
Africa	2	3	15
Asia Pacific	13	35	13
Europe	6	55	15
Latin America	9	35	15
North America	2	45	12
Global	**32**	**173**	**14**
Developing MS[a]	16	136	14
Developed MS	16	37	14

[a] MS means Member States

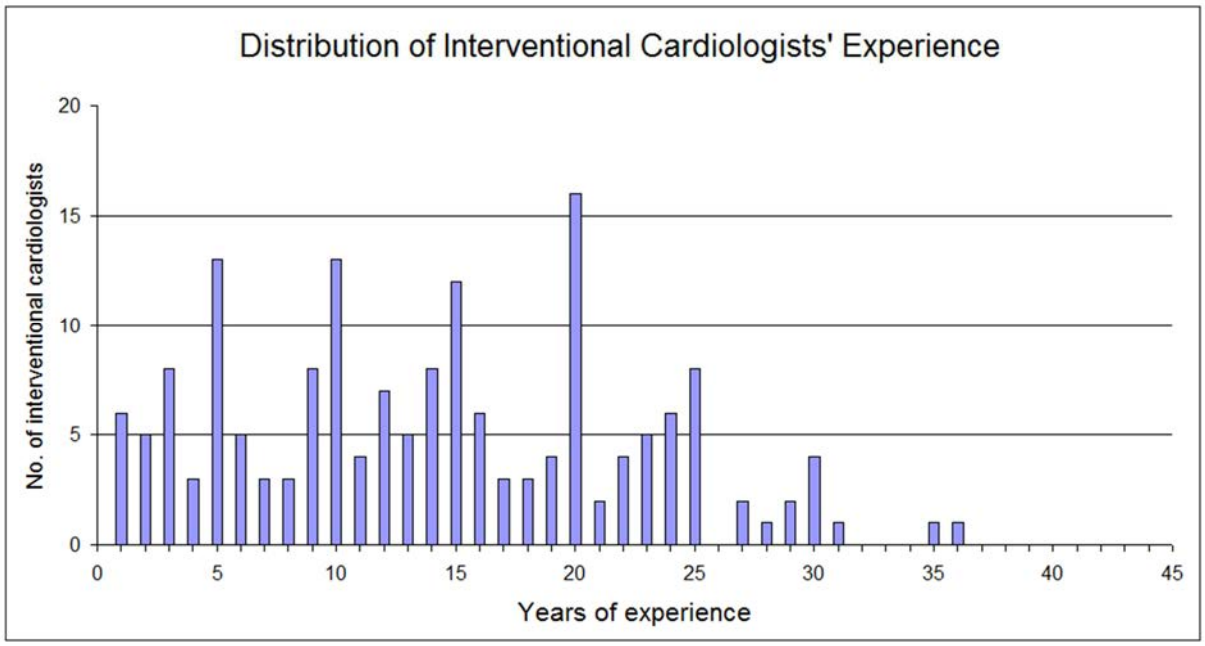

FIG. 4. Distribution of the number of years of experience of the surveyed interventional cardiologists.

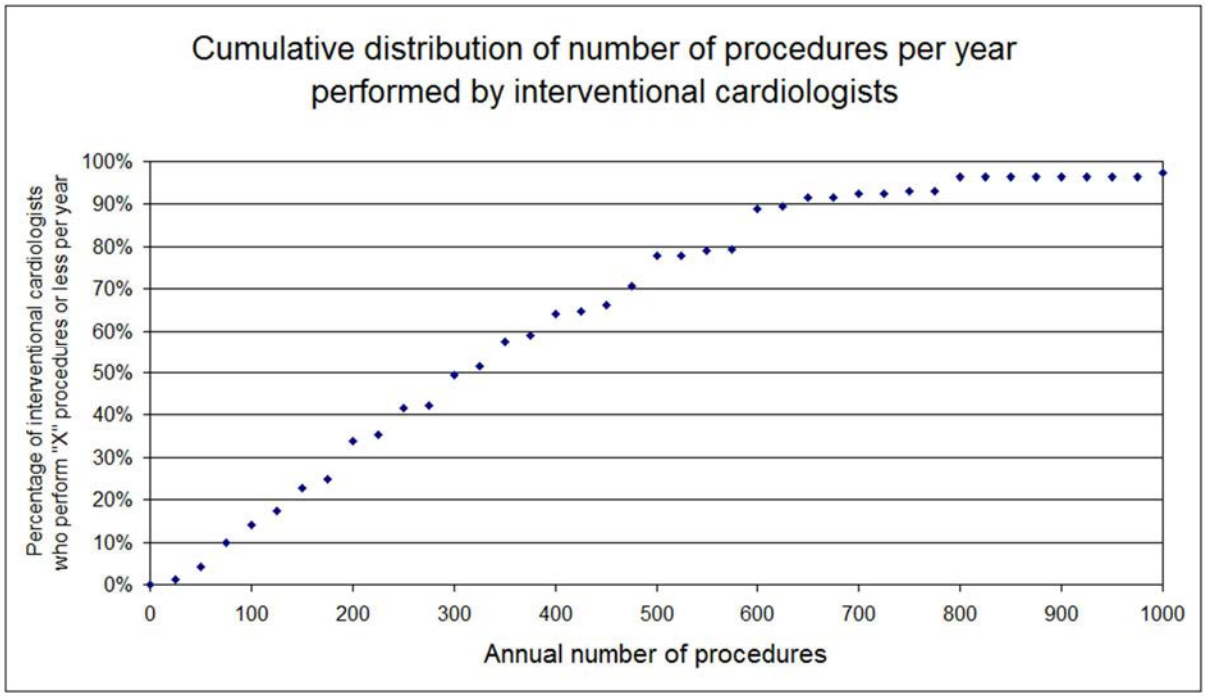

FIG. 5. Cumulative distribution of the number of procedures performed by surveyed interventional cardiologists per year.

I.2.3. Use of personal dosimeters

TABLE 9. NUMBERS AND PERCENTAGES OF INTERVENTIONAL CARDIOLOGISTS USING INDIVIDUAL DOSIMETERS, BY REGION

Region	Total regional number of interventional cardiologists	Number of interventional cardiologists:					
		Use of individual dosimeter(s)			Use of two dosimeters		
		Always	*Never*	*Sometimes*	*Always*	*Never*	*Sometimes*
Africa	3	1 (33)*	2 (67)	0 (0)	0 (0)	3 (100)	0 (0)
Asia Pacific	62	55 (89)	0 (0)	7 (11)	43 (69)	16 (26)	3 (5)
Europe	56	47 (84)	2 (4)	7 (12)	22 (39)	20 (36)	14 (25)
Latin America	35	18 (51)	4 (12)	13 (37)	6 (17)	27 (77)	2 (6)
North America	45	32 (71)	3 (7)	10 (22)	20 (44)	20 (44)	5 (12)
Global	**201**	**153 (76)**	**11 (6)**	**37 (18)**	**91 (45)**	**86 (43)**	**24 (12)**
Developing MS[a]	37	26 (70)	3 (8)	8 (22)	9 (24)	26 (70)	2 (6)
Developed MS	164	127 (77)	8 (5)	29 (18)	82 (50)	60 (37)	22 (13)

* Values in parentheses are percentages of the corresponding total. [a] MS means Member States.

I.2.4. Use of protective clothing and protective tools

TABLE 10. NUMBERS AND PERCENTAGES OF INTERVENTIONAL CARDIOLOGISTS USING PROTECTIVE CLOTHING, BY REGION

Region	Total regional number of interventional cardiologists	Number of interventional cardiologists:					
		Use of a protective apron			Use of protective eyewear		
		Always	*Never*	*Sometimes*	*Always*	*Never*	*Sometimes*
Africa	3	3 (100)*	0 (0)	0 (0)	0 (0)	2 (67)	1 (33)
Asia Pacific	62	61 (98)	0 (0)	1 (2)	22 (35)	31 (50)	9 (15)
Europe	56	56 (100)	0 (0)	0 (0)	27 (48)	13 (23)	16 (29)
Latin America	35	30 (86)	3 (8)	2 (6)	10 (29)	11 (31)	14 (40)
North America	45	45 (100)	0 (0)	0 (0)	27 (60)	11 (24)	7 (16)
Global	**201**	**195 (97)**	**3 (1.5)**	**3 (1.5)**	**86 (43)**	**68 (34)**	**47 (23)**
Developing MS[a]	37	36 (97)	0 (0)	1 (3)	9 (24)	16 (43)	12 (33)
Developed MS	164	159 (97)	3 (2)	2 (1)	77 (47)	52 (32)	35 (21)

* Values in parentheses are percentages of the corresponding total. [a] MS means Member States.

TABLE 11. NUMBERS AND PERCENTAGES OF INTERVENTIONAL CARDIOLOGISTS USING PROTECTIVE TOOLS, BY REGION

Region	Total regional number of interventional cardiologists	Number of interventional cardiologists:					
		Use of a ceiling screen			Use of table curtains		
		Always	*Never*	*Sometimes*	*Always*	*Never*	*Sometimes*
Africa	3	1 (33)*	1 (33)	1 (33)	1 (33)	2 (67)	0 (0)
Asia Pacific	62	56 (90)	1 (2)	5 (8)	57 (92)	1 (2)	4 (6)
Europe	56	41 (73)	2 (4)	13 (23)	45 (80)	9 (16)	2 (4)
Latin America	35	16 (46)	7 (20)	12 (34)	15 (43)	13 (37)	7 (20)
North America	45	43 (96)	0 (0)	2 (4)	36 (80)	3 (7)	6 (13)
Global	**201**	**157 (78)**	**11 (6)**	**33 (16)**	**154 (77)**	**28 (14)**	**19 (9)**
Developing MSa	37	22 (59)	5 (14)	10 (27)	23 (62)	9 (24)	5 (14)
Developed MS	164	135 (82)	6 (4)	23 (14)	131 (80)	19 (12)	14 (8)

* Values in parentheses are percentages of the corresponding total. [a] MS means Member States.

I.2.5. Knowledge of personal and patient doses in IC

TABLE 12. NUMBERS AND PERCENTAGES, BY REGION, OF INTERVENTIONAL CARDIOLOGISTS AND THEIR KNOWLEDGE OF PERSONAL AND PATIENT DOSES IN INTERVENTIONAL CARDIOLOGY

Region	Total regional number of interventional cardiologists	Number of interventional cardiologists:			
		Knowledge of personal doses		Knowledge of patient doses	
		Yes	*No*	*Yes*	*No*
Africa	3	1 (33)*	2 (67)	0 (0)	3 (100)
Asia Pacific	62	52 (84)	10 (16)	45 (73)	17 (27)
Europe	56	43 (77)	13 (23)	24 (43)	32 (57)
Latin America	35	14 (40)	21 (60)	5 (14)	30 (86)
North America	45	19 (42)	26 (58)	12 (27)	33 (73)
Global	**201**	**129 (64)**	**72 (36)**	**86 (43)**	**115 (57)**
Developing MS[a]	37	21 (57)	16 (43)	12 (32)	25 (68)
Developed MS	164	108 (66)	56 (34)	74 (45)	90 (55)

* Values in parentheses are percentages of the corresponding total. [a] MS means Member States.

I.2.6. Radiation protection training and certification of interventional cardiologists

TABLE 13. NUMBERS AND PERCENTAGES OF INTERVENTIONAL CARDIOLOGISTS WITH RADIATION PROTECTION TRAINING AND RADIATION PROTECTION CERTIFICATION, BY REGION

Region	Total regional number of interventional cardiologists	Number of interventional cardiologists:			
		Radiation protection training?		Certification in radiation protection?	
		Yes	*No*	*Yes*	*No*
Africa	3	1 (33)*	2 (67)	0 (0)	3 (100)
Asia Pacific	62	58 (94)	4 (6)	41 (66)	21 (34)
Europe	56	45 (80)	11 (20)	34 (61)	22 (39)
Latin America	35	21 (60)	14 (40)	12 (34)	23 (66)
North America	45	42 (93)	3 (7)	17 (38)	28 (62)
Global	**201**	**167 (83)**	**34 (17)**	**104 (52)**	**97 (48)**
Developing MS[a]	37	29 (78)	8 (22)	15 (41)	22 (59)
Developed MS	164	138 (84)	26 (16)	89 (54)	75 (46)

* Values in parentheses are percentages of the corresponding total. [a] MS means Member States.

TABLE 14. INFLUENCE OF RADIATION PROTECTION TRAINING AND CERTIFICATION OF INTERVENTIONAL CARDIOLOGISTS IN THEIR WEARING OF DOSIMETERS, USE OF PROTECTIVE TOOLS AND THEIR KNOWLEDGE OF DOSES

Number of interventional cardiologists with:	**RP certification**	**RP training**	**No RP training**	**All**
	104	*167*	*34*	**201**
For each column, number of interventional cardiologists who:				
Always wear a dosimeter	91 (88)*	134 (80)	19 (56)	**153 (76)**
Always wear 2 dosimeters	59 (57)	82 (49)	9 (26)	**91 (45)**
Use a protective apron	104 (100)	166 (99)	29 (85)	**195 (97)**
Use protective eye wear	48 (46)	72 (43)	14 (41)	**86 (43)**
Use ceiling screen	82 (79)	133 (80)	24 (71)	**157 (78)**
Use table curtains	82 (79)	134 (80)	20 (59)	**154 (77)**
Know personal doses	85 (82)	117 (70)	12 (35)	**129 (64)**
Know patient doses	62 (60)	82 (49)	4 (12)	**86 (43)**

* Values in parentheses are percentages of the corresponding total.

I.3. RESULTS FROM THE QUESTIONNAIRE TO REGULATORY BODIES

The principal findings from the regulatory body questionnaire are given in Section 2.3 of the main document. This appendix gives additional data in the form of tables and figures. Note, not all questions were answered by all the responders.

I.3.1. Responses to the questionnaire

TABLE 15. NUMBERS OF REGULATORY BODIES CONTACTED, AND NUMBERS AND PERCENTAGES (IN PARENTHESES) OF RESPONSES RECEIVED; AND THE WORLD POPULATION REPRESENTED

Region	Countries contacted	Countries responded	RBs[a] contacted	RB responses	Total regional population, 10^6	Total population of responding countries, 10^6
Africa	35	10	35	10 (29)*	1000	212 (21)
Asia Pacific	29	14	37	17 (46)	3879	815 (21)
Europe	49	26	49	26 (53)	731	222 (30)
Latin America	21	5	21	5 (24)	679	151 (22)
North America	2	2	49	23 (47)	341	212 (62)
Global	**136**	**57**	**191**	**81 (42)**	**6630**	**1612 (24)**

* Values in parentheses are percentages of the corresponding total. [a] RB means regulatory body.

I.3.2. Personal doses in interventional cardiology procedures

TABLE 16. DATA REPORTED BY REGULATORY BODIES ON THE NUMBERS OF PERSONNEL IN INTERVENTIONAL CARDIOLOGY BEING MONITORED

Region	No. of RBs[a] with data on numbers of personnel in IC being monitored	Number of monitored IC physicians	Number of monitored other IC professionals	Total number of monitored personnel in IC	Ratio of monitored IC physicians to total monitored IC personnel
Africa	4	19	44	63	**0.30**
Asia Pacific	5	173	392	565	**0.31**
Europe	13	325	564	889	**0.37**
Latin America	2	45	45	90	**0.50**
North America	1	138	162	300	**0.46**
Global	**25**	**700**	**1207**	**1907**	**0.37***
Developed MS[b]	16	495	808	1303	**0.38**
Developing MS	9	205	399	604	**0.34**

[a] RB means regulatory body. [b] MS means Member States.

* The figure of 0.37 monitored physicians per total monitored workers in IC is in good agreement with the result from the IC facilities' questionnaire, where a figure of about 0.4 was also reported (see Table 3).

TABLE 17. DATA ON NUMBERS OF REGULATORY BODIES WITH PERSONAL DOSE DATA FOR INTERVENTIONAL CARDIOLOGY

Region	Countries responded	RBs[a] responded	Number of RBs* with valid** personal dose data for IC
Africa	10	10	4 (40)***
Asia Pacific	14	17	9 (53)
Europe	26	26	13 (50)
Latin America	5	5	2 (40)
North America	2	23	1 (4)
Global	**57**	**81**	**29 (36)**
Developed MS[b]	35	59	19 (32)
Developing MS	22	22	10 (45)

[a] RB means regulatory body. [b] MS means Member States.

* Not all regulatory bodies had data for all categories of persons in IC.

** Valid means that the dose data were available, the dosimetry was robust, and the data were for IC workers only.

*** Values in parentheses are percentages of the corresponding total.

TABLE 18. DISTRIBUTIONS OF COUNTRY MEDIAN AND THIRD QUARTILE ANNUAL EFFECTIVE DOSES FROM THE REGULATORY BODIES' REPORTED DATA FOR INTERVENTIONAL CARDIOLOGISTS, FOR THE YEARS 2006 TO 2008.

	Median doses (mSv)			Third quartile doses (mSv)		
	2006	*2007*	*2008*	*2006*	*2007*	*2008*
Average	**0.67**	**0.78**	**0.73**	**1.80**	**1.35**	**1.09**
Standard deviation	0.64	0.60	0.62	2.54	1.25	0.69
Minimum	0.02	0.02	0.02	0.39	0.03	0.11
1st quartile	0.29	0.32	0.32	0.47	0.49	0.60
Median	**0.34**	**0.64**	**0.56**	**0.72**	**0.80**	**0.87**
3rd quartile	1.00	1.06	1.04	1.96	2.05	1.47
Maximum	2.52	2.14	2.82	10.2	5.42	2.41

Note: Not all regulatory bodies supplied dose data for both medians and third quartiles for all years.

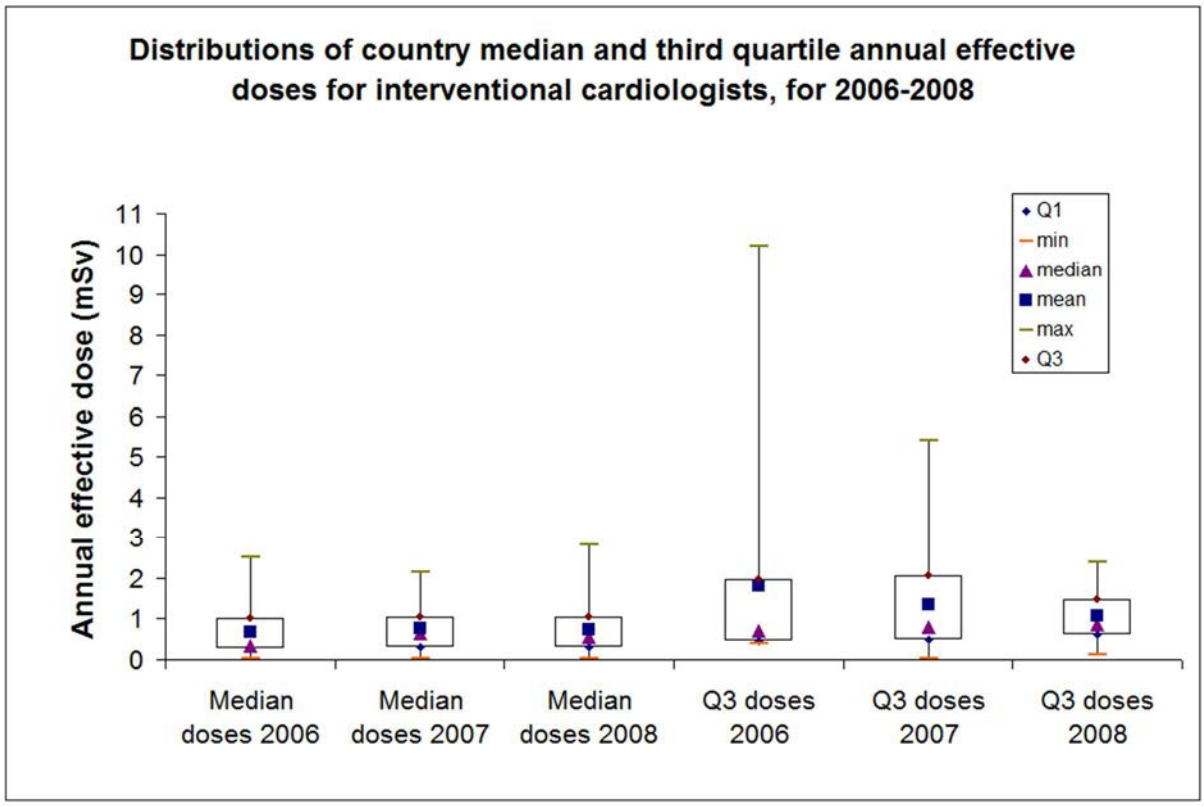

FIG. 6. Distributions of country median and third quartile annual effective doses from the regulatory bodies' reported data for interventional cardiologists, for the years 2006 to 2008.

TABLE 19. DISTRIBUTIONS OF COUNTRY MEDIAN AND THIRD QUARTILE ANNUAL EFFECTIVE DOSES FROM THE REGULATORY BODIES' REPORTED DATA FOR OTHER WORKERS IN IC, FOR THE YEARS 2006 TO 2008

	Median doses (mSv)			**Third quartile doses (mSv)**		
	2006	*2007*	*2008*	*2006*	*2007*	*2008*
Average	**0.42**	**1.07**	**0.76**	**1.28**	**1.46**	**1.10**
Standard deviation	0.38	1.17	0.68	1.06	1.12	1.09
Minimum	0.04	0.02	0.02	0.09	0.04	0.04
1st quartile	0.26	0.34	0.33	0.59	0.67	0.45
Median	**0.31**	**0.60**	**0.45**	**1.17**	**1.22**	**0.69**
3rd quartile	0.42	1.50	1.08	1.46	1.76	1.41
Maximum	1.44	4.49	2.52	3.59	3.73	4.15

Note: Not all regulatory bodies supplied dose data for both medians and third quartiles for all years.

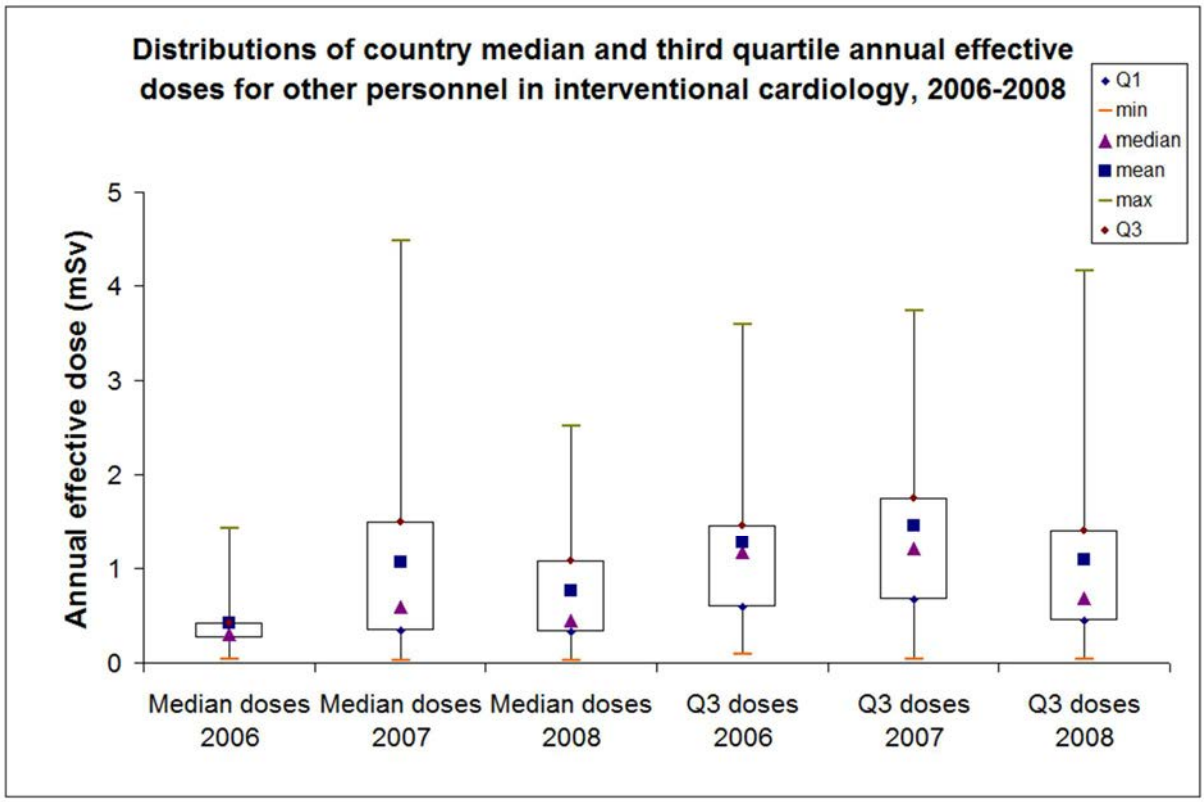

FIG. 7. Distributions of country median and third quartile annual effective doses from the regulatory bodies' reported data for other personnel in interventional cardiology, for the years 2006 to 2008.

TABLE 20. DISTRIBUTIONS OF COUNTRY MEDIAN AND THIRD QUARTILE ANNUAL EFFECTIVE DOSES FROM THE REGULATORY BODIES' REPORTED DATA WHERE ONLY DATA FOR COMBINED WORKERS IN IC WERE GIVEN, FOR THE YEARS 2006 TO 2008

	Median doses (mSv)			**Third quartile doses (mSv)**		
	2006	*2007*	*2008*	*2006*	*2007*	*2008*
Average	**0.59**	**0.76**	**0.56**	-	-	**1.68**
Standard deviation	0.34	0.39	0.47	-	-	0.21
Minimum	0.30	0.28	0.10	-	-	1.47
1st quartile	0.35	0.48	0.26	-	-	1.58
Median	**0.40**	**0.73**	**0.39**	-	-	**1.68**
3rd quartile	0.74	1.01	0.69	-	-	1.79
Maximum	1.07	1.32	1.35	-	-	1.89

Note: Not all regulatory bodies supplied dose data for both medians and third quartiles for all years.

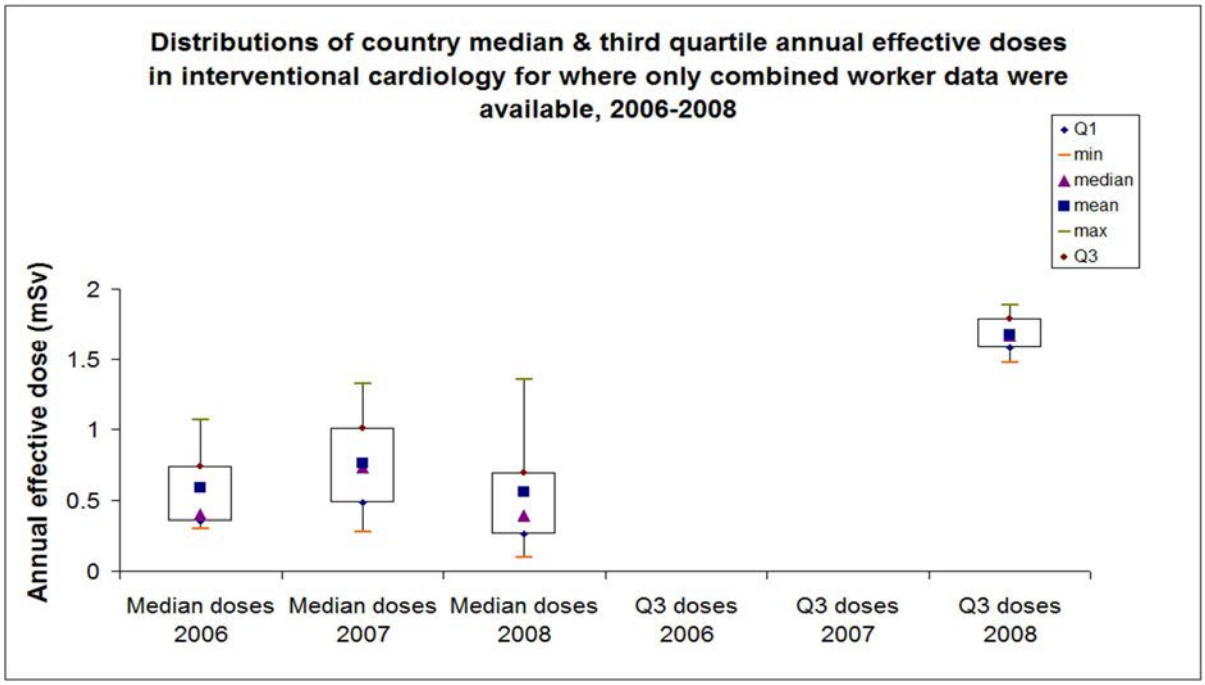

FIG. 8. Distributions of country median and third quartile annual effective doses from the regulatory bodies' reported data for where only combined occupational data were available, for the years 2006 to 2008.

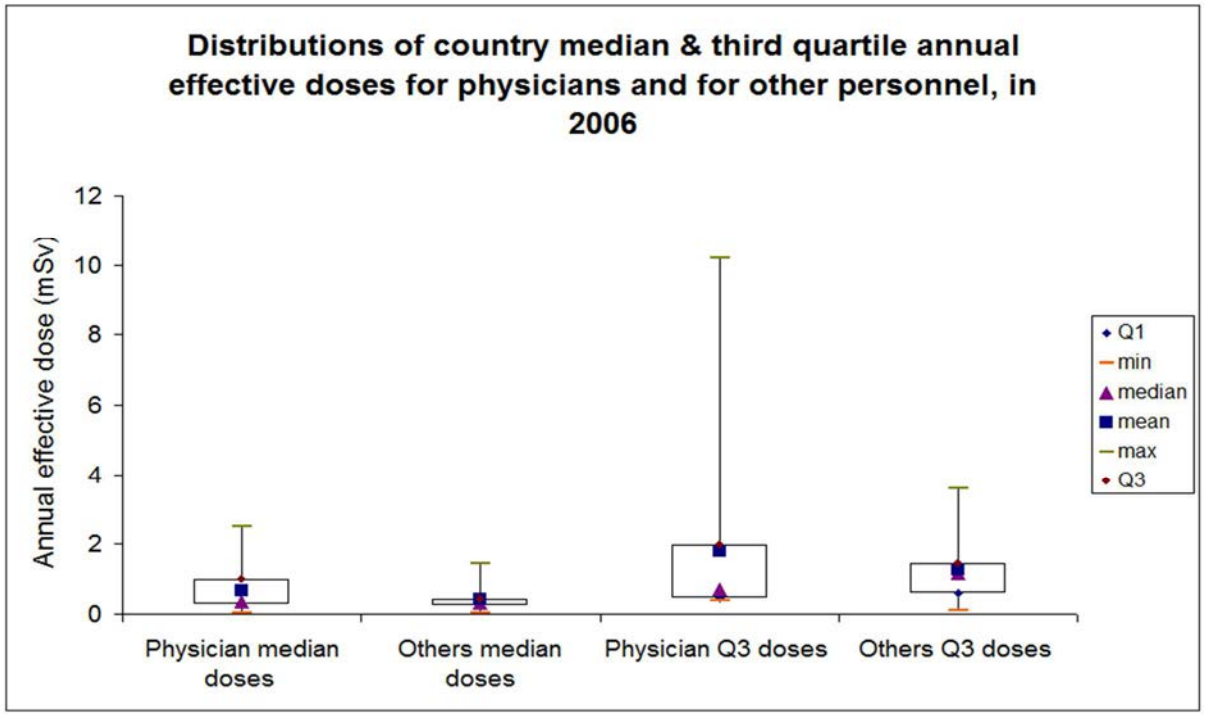

FIG. 9. Distributions of country median and third quartile annual effective doses for IC physicians and for other IC personnel, in 2006.

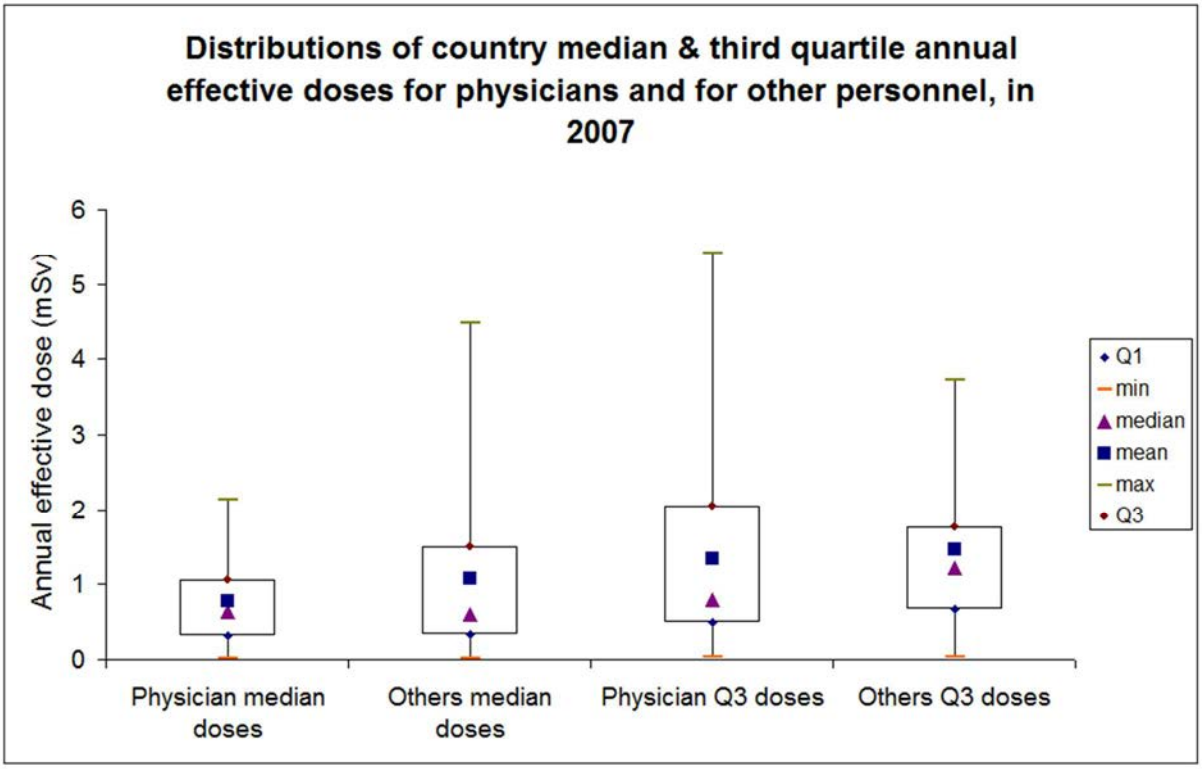

FIG. 10. Distributions of country median and third quartile annual effective doses for IC physicians and for other IC personnel, in 2007.

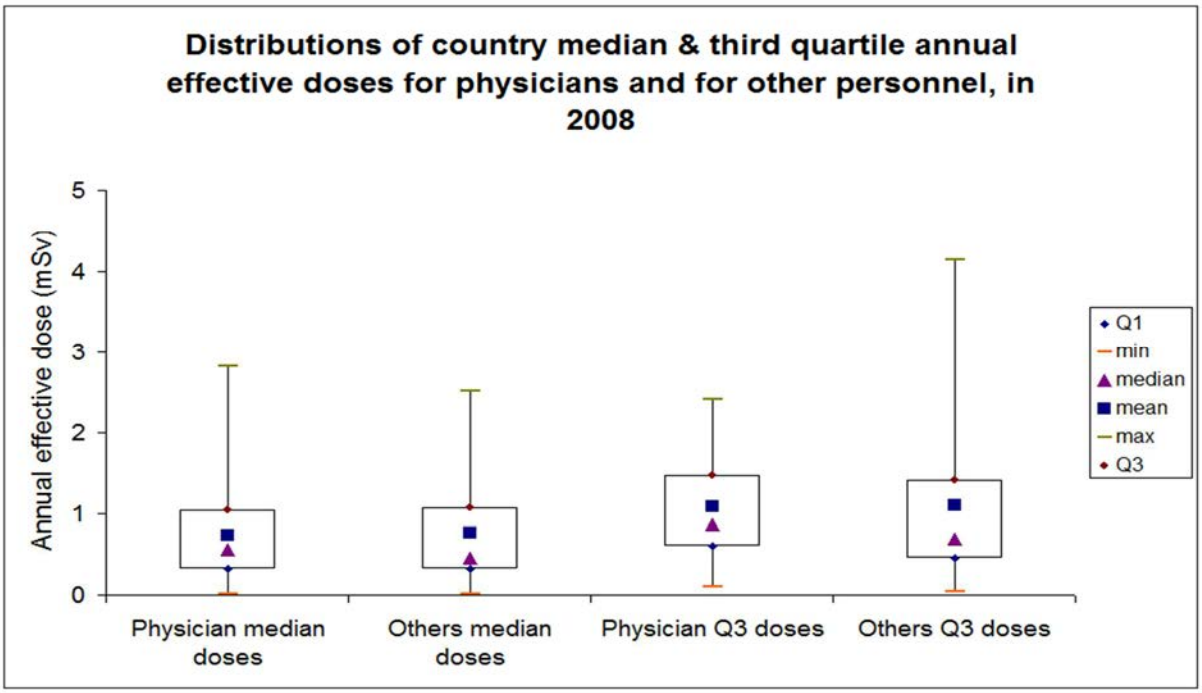

FIG. 11. Distributions of country median and third quartile annual effective doses for IC physicians and for other IC personnel, in 2008.

I.3.3. Number and position of dosimeters in IC

TABLE 21. NUMBER AND PERCENTAGE OF REGULATORY BODIES MANDATING THE NUMBER OF, AND POSITION OF, PERSONAL DOSIMETERS FOR MONITORING IN INTERVENTIONAL CARDIOLOGY

Region	**Number of responding RBs[a]**	**Number and position mandated by the RB?**		
		Yes	*No*	*Not answered*
Africa	10	3 (30)*	4 (40)	3 (30)
Asia Pacific	16	8 (50)	8 (50)	0 (0)
Europe	26	19 (73)	7 (27)	0 (0)
Latin America	5	2 (40)	2 (40)	1 (20)
North America	22	13 (59)	8 (36)	1 (5)
Global	**79**	**45 (57)**	**29 (37)**	**5 (6)**
Developing MS[b]	22	10 (46)	8 (36)	4 (18)
Developed MS	57	35 (61)	21 (37)	1 (2)

* Values in parentheses are percentages of the corresponding total.

[a] RB means regulatory body. [b] MS means Member States.

TABLE 22. DETAILS ON THE MANDATED NUMBER OF PERSONAL DOSIMETERS IN INTERVENTIONAL CARDIOLOGY

Region	**No. of RBs[a] mandating the number of dosimeters**	**Number of dosimeters required:**			
		1	***2***	***3***	***Not specified***
Africa	3	1	1	0	1
Asia Pacific	8	0	2	0	6
Europe	19	10	2	1	6
Latin America	2	0	1	0	1
North America	13	7	3	0	3
Global	**45**	**18 (40*)**	**9 (20)**	**1 (2)**	**17 (38)**

* Values in parentheses are percentages of the corresponding total.

[a] RB means regulatory body.

TABLE 23. DETAILS ON THE MANDATED WEARING POSITIONS OF PERSONAL DOSIMETERS IN INTERVENTIONAL CARDIOLOGY WHEN THE WEARING OF ONE DOSIMETER WAS MANDATED

Region	Number of RBs[a] mandating only one dosimeter	Mandated wearing position:					
		Worn above the apron:			Worn below the apron:		
		Chest or trunk	*Collar or shoulder*	*Unspecified*	*Chest or trunk*	*Collar or shoulder*	*Unspecified*
Africa	1				1		
Asia Pacific	0						
Europe	10	4	2	2	2		
Latin America	0						
North America	7		7				
Global	**18**	**4**	**9**	**2**	**3**	**0**	**0**

[a] RB means regulatory body.

I.3.4. Regulatory requirements for radiation protection in interventional cardiology

TABLE 24. NUMBER (AND PERCENTAGE) OF REGULATORY BODIES MANDATING RADIATION PROTECTION TRAINING FOR PERSONS IN ORDER TO BE ABLE TO PERFORM INTERVENTIONAL CARDIOLOGY PROCEDURES

Region	Number of responding RBs[a]	Is radiation protection training for working in IC mandated?		
		Yes	*No*	*Not Answered*
Africa	10	3 (30)*	4 (40)	3 (30)
Asia Pacific	17	10 (59)	7 (41)	0 (0)
Europe	25	16 (64)	9 (36)	0 (0)
Latin America	5	1 (20)	3 (60)	1 (20)
North America	23	11 (48)	12 (52)	0 (0)
Global	**80**	**41 (51)**	**35 (44)**	**4 (5)**
Developing MS[b]	22	8 (36)	10 (46)	4 (18)
Developed MS	58	33 (57)	25 (43)	0 (0)

* Values in parentheses are percentages of the corresponding total.

[a] RB means regulatory body. [b] MS means Member States.

I.4. THE QUESTIONS FROM THE QUESTIONNAIRES

I.4.1. Questions from the Chief Interventional Cardiologists' questionnaire

1. Number of operators with personal dosimetry involved (in 2008) in Interventional Cardiology and Electrophysiology procedures:

— Total no. of monitored workers:

— Physicians:

— Nurses:

— Other professionals:

2. Number of cardiac cath labs:

3. Total number of procedures performed in cardiac cath labs in 2008:

4. Age of the most used x ray system in the cardiac cath lab:

<5 y,

5-10,

>10.

I.4.2. Questions from the Individual Interventional Cardiologists' questionnaire

1. Years of experience as an interventional cardiologist:

2. Number of procedures performed in 2008:

3. Do you use regularly your personal dosimeter(s)?

Always Never Sometimes

4. Do you use 2 personal dosimeters?

Always Never Sometimes

5. Do you know your personal doses?

Yes No

6. Are you using a protective apron?

Always Never Sometimes

7. Are you using protective eyewear?

Always Never Sometimes

8. Are you using a ceiling protective screen?

Always Never Sometimes

9. Are you using protective curtains under the table?

Always Never Sometimes

10. Do you know your patients' doses?

Yes No

11. Have you had training in radiation protection?

Yes No

12. Have you a certification in radiation protection?

Yes No

I.4.3. Questions from the Regulatory Body's questionnaire

1. Number of workers with personal dosimetry involved (in 2008) in Interventional Cardiology procedures:

— Total no. of monitored workers :

— physicians:

— other professionals:

— Information not available:

2. Values of occupational doses (effective dose) existing in the database of the national authority (or database accessible by the national authority):

Effective dose (mSv/year)	**Physicians**	**Other professionals**	**All**
Median value in 2008			
3rd quartile in 2008			
Median value in 2007			
3rd quartile in 2007			
Median value in 2006			
3rd quartile in 2006			

— Information not available:

3. Does the Radiation Protection Regulatory Body define the number and position of dosimeters for staff monitoring in Interventional Cardiology?

— yes:

— no :

4. Does the Radiation Protection Regulatory Body require a person to have specific radiation protection training to perform fluoroscopy in interventional cardiology?

— yes:

— no :

5. Does the Radiation Protection Regulatory Body require a person to have a specific licence or certification in radiation protection to perform fluoroscopy in interventional cardiology?

— yes:

— no :

APPENDIX II. DETAILED RESULTS OF THE PILOT SURVEY ON OBTAINING OCCUPATIONAL EXPOSURE DATA IN INTERVENTIONAL CARDIOLOGY

The principal findings from the pilot survey are given in Section 3 of the main document. This appendix gives additional data in the form of tables and figures. Not all data were provided for all IC personnel in a given IC facility.

II.1. RESPONSES TO THE SURVEY

TABLE 25. DETAILS ON IC FACILITIES PARTICIPATING IN THE SURVEY

Regions	**Number of countries**	**Number of IC facilities**	**IC, tot[1]**	**EP, tot[2]**	**N, tot[3]**	**T, tot[4]**
Asia-Pacific	4	6	84	18	54	52
Europe	8	13	96	2	95	29
Latin America	3	5	34	4	14	11
North America	1	2	133	25	47	34
Global	**16**	**26**	**347**	**49**	**210**	**126**

[1] 'IC, tot'means all interventional cardiologists, regardless of status.
[2] 'EP, tot' means all electrophysiologists, regardless of status.
[3] 'N, tot' means all nurses, regardless of status.
[4] 'T, tot' means all technicians, technologists or radiographers, regardless of status.

II.2. NUMBERS OF FACILITIES, PERSONNEL AND PROCEDURES IN IC

TABLE 26. NUMBERS OF FACILITIES AND PHYSICIANS PARTICIPATING IN THE SURVEY

	IC, s[1]	IC, t[2]	IC, ?[3]	IC, tot[4]	EP, s[5]	EP, t[6]	EP, ?[7]	EP, tot[8]	All Dr[9]
No facilities	25	10	1	26	8	2	1	9	26
No of participating physicians	195	75	77	347	36	2	11	49	414
Physicians per facility, for those facilities with participating physicians of the given type:									
Mean	7.8	7.5	77.0	13.4	4.5	1.0	11.0	5.4	15.9
Minimum	1	1	-	1	1	1	-	2	1
Median	6	4	77	9	2.5	1	11	3	10
Maximum	31	25	-	77	13	1	-	14	88

[1, 2, 3, 4] 'IC, s' means consultant or qualified interventional cardiologist; 'IC, t' means trainee interventional cardiologist; 'IC, ?' means an interventional cardiologist of unspecified status; 'IC, tot' means all interventional cardiologists, regardless of status.
[5, 6, 7, 8] 'EP, s' means consultant or qualified electrophysiologist; 'EP, t' means trainee electrophysiologist; 'EP, ?' means an electrophysiologist of unspecified status; 'EP, tot' means all electrophysiologists, regardless of status.
[9] 'All Dr' (last column) means all participating physicians from a facility, and includes 18 physicians that were neither interventional cardiologists nor electrophysiologists.

Note, it was not known if all the interventional cardiologists and electrophysiologists at any given facility were included in the survey response for that facility. It would appear from some of the responses, at least, that not all physicians from a given facility were included in that facility's response.

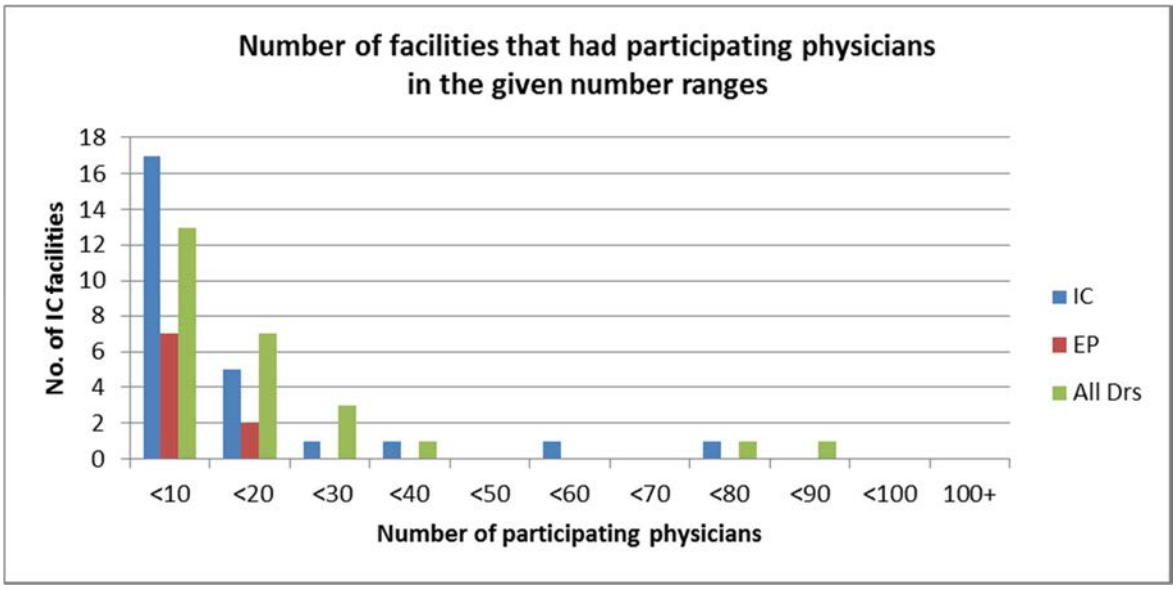

FIG. 12. Number of facilities as a function of the number of participating physicians.

TABLE 27. NUMBERS OF FACILITIES AND NON-PHYSICIAN PROFESSIONALS PARTICIPATING IN THE SURVEY

	N, s[1]	N, t[2]	N, ?[3]	N, tot[4]	T, s[5]	T, ?[6]	T, tot[7]	T/N, ?[8]	Total
No facilities	17	1	2	19	14	1	15	3	21
No of participating physicians	179	2	29	210	93	33	126	102	438
Non-physician professionals per facility, for those facilities with participating professionals of the given type:									
Mean	10.5	2	14.5	11.1	6.6	33	8.4	34	20.9
Minimum	2	-	4	2	1	-	1	1	3
Median	7	-	14.5	7	4	-	4	7	9
Maximum	47	-	25	47	34	-	34	94	94

[1, 2, 3, 4] 'N, s' means qualified nurse; 'N, t' means trainee nurse; 'N, ?' means a nurse of unspecified status; 'N, tot' means all nurses, regardless of status.
[5, 6, 7, 8] 'T, s' means qualified technician, technologist or radiographer; 'T, ?' means qualified technician, technologist or radiographer of unspecified status; 'T, tot' means all technicians, technologists or radiographers, regardless of status; 'T/N, ?' means a non-physician health professional of unknown profession or status.

Note, it was not known if all the non-physician health professionals at any given facility were included in the survey response for that facility.

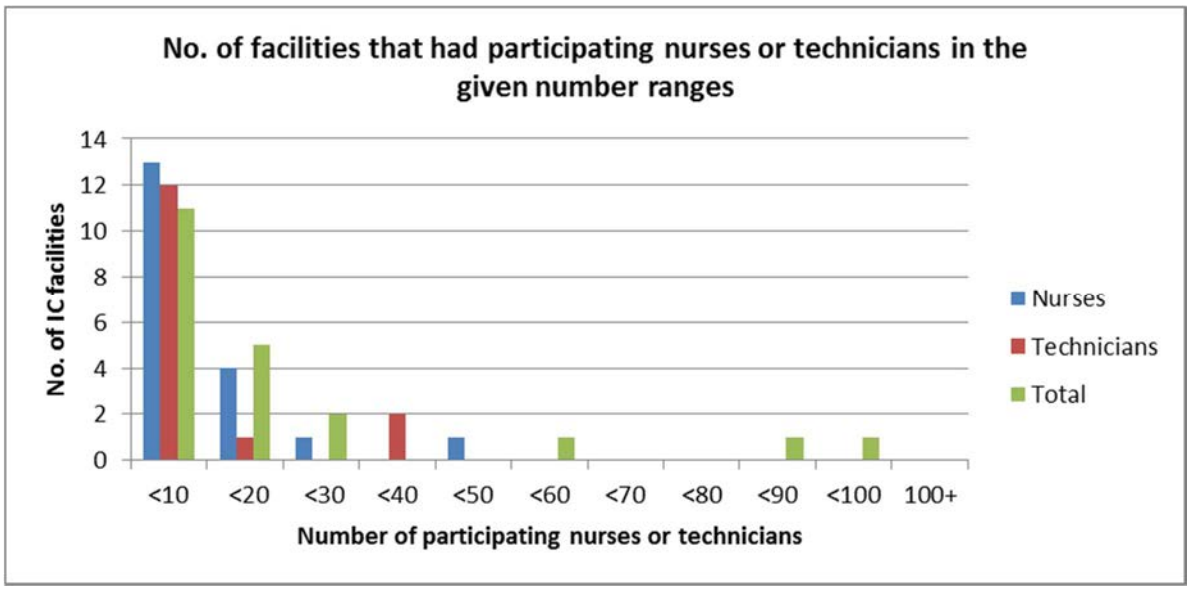

FIG. 13. Number of facilities as a function of the number of participating nurses and technicians.

TABLE 28. NUMBER OF PROCEDURES PERFORMED BY PHYSICIANS PER YEAR IN A GIVEN FACILITY[1]

	No. of responses	Mean	Minimum	Median	Maximum
Interventional cardiologists	258	248	1	177	1394
Electrophysiologists	45	189	43	182	496
Other physicians	11	340	23	150	1285
Qualified interventional cardiologists	149	321	10	277	1394
Trainee interventional cardiologists	43	181	1	162	674
Qualified electrophysiologists	34	177	43	176	496

[1] Some physicians may work in other facilities as well, but this was not relevant to this survey as it is the dose-workload relationship in a given facility that is of importance for a given physician.

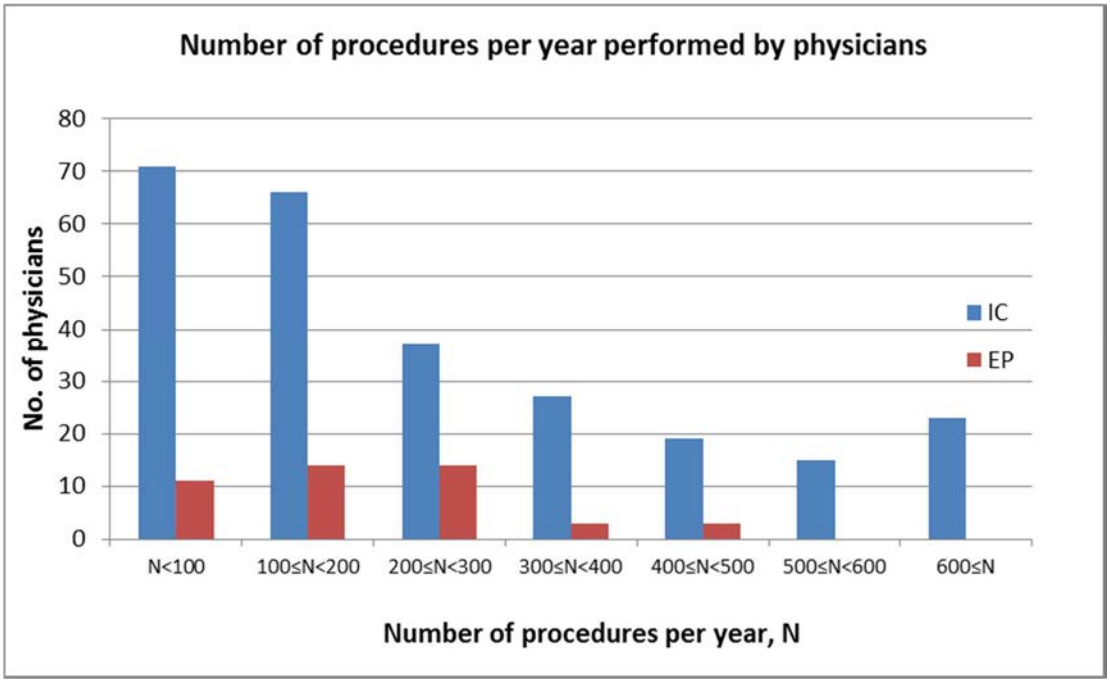

FIG. 14. Distribution of the reported number of procedures being performed per year by interventional cardiologists and electrophysiologists in a given facility.

TABLE 29. NUMBER OF PROCEDURES PER YEAR BY NON-PHYSICIAN PERSONNEL IN A GIVEN FACILITY

	No. of responses	Mean	Minimum	Median	Maximum
Nurses	47	317	2	250	667
Technicians[1]	41	448	73	484	1025
Unspecified – nurse or technician	71	482	1	518	1130

[1] The term technician here covers technicians, technologists and radiographers.

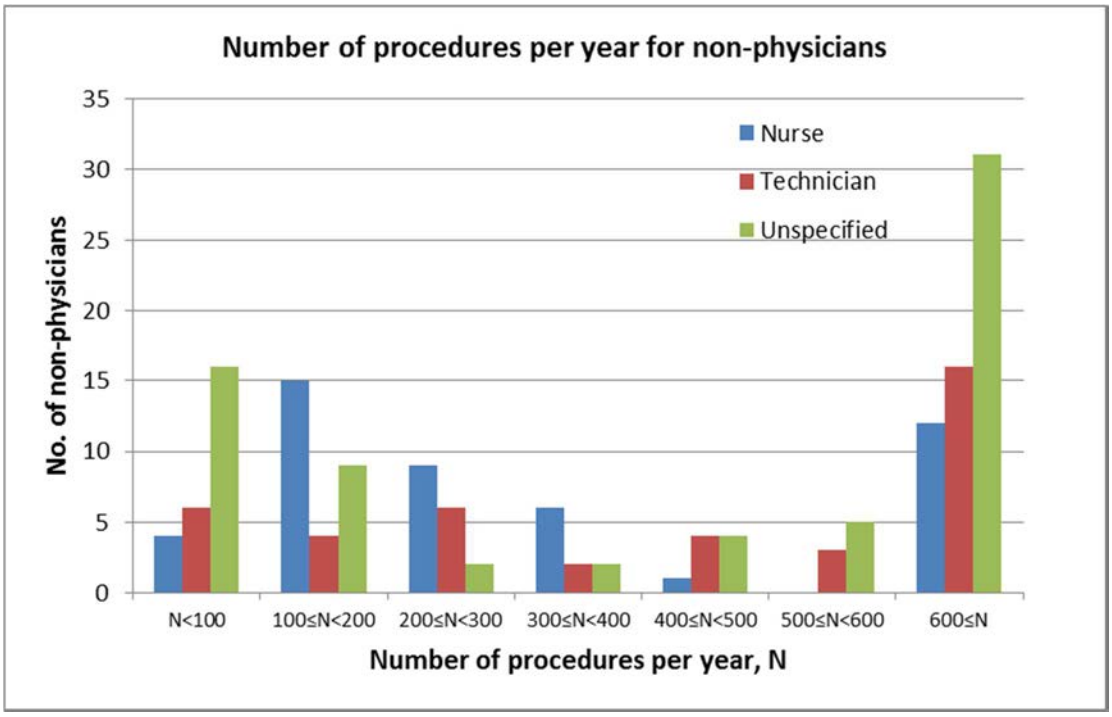

FIG. 15. Distribution of the reported number of procedures for non-physicians per year in a given facility.

II.3. MONITORING PERIODS AND NUMBERS OF DOSIMETERS WORN

TABLE 30. NUMBER OF MONITORING PERIODS PER YEAR FOR THE PARTICIPATING IC FACILITIES AND PERSONNEL

Number of monitoring periods per year	Number of IC facilities	Number of participating physicians
4	5	96
6	4	34
11	1	14
12	14	107
Not specified	2	163
Total	**26**	**414**

TABLE 31. NUMBER OF DOSIMETERS WORN AT THE PARTICIPATING IC FACILITIES AND BY THE PERSONNEL

Number of dosimeters worn by physicians	**Number of IC facilities**	**Number of participating physicians**
2 dosimeters (over-apron and under-apron)	7	163
1 dosimeter, over-apron	5	108
1 dosimeter, under-apron	13	143
Extremity dosimeter	5	25
Lens dosimeter	1	88
Number of dosimeters worn by non-physicians	**Number of IC facilities**	**Number of participating non-physicians**
2 dosimeters (over-apron and under-apron)	4	129
1 dosimeter, over-apron	6	140
1 dosimeter, under-apron	10	169
Extremity dosimeter	2	22
Lens dosimeter	1	94

II.4. QUALITY OF THE DOSE DATA REPORTED

TABLE 32. NUMBER OF MONITORING PERIODS WITH REPORTED DOSES, D, FOR THE PARTICIPATING PHYSICIANS EQUAL TO ZERO, AND GREATER THAN OR EQUAL TO ZERO

Total number of monitoring periods reported	2026
Number of monitoring periods with $D \geq 0$	1691
Percentage of monitoring periods with $D \geq 0$	83.5%
Total number of monitoring periods reported, using an under-apron dosimeter	1648
Number of under apron monitoring periods with $D \geq 0$	1509
Percentage of under apron monitoring periods with $D \geq 0$	91.6%
Number of under apron monitoring periods with $D = 0$	824
Percentage of under apron monitoring periods with $D = 0$	54.6%
Total number of monitoring periods reported, using an over-apron dosimeter	888
Number of over apron monitoring periods with $D \geq 0$	625
Percentage of over apron monitoring periods with $D \geq 0$	70.4%
Number of over apron monitoring periods with $D = 0$	206
Percentage of over apron monitoring periods with $D = 0$	33.0%

TABLE 33. QUALITY FACTORS USED TO ASSESS THE RAW REPORTED DOSE DATA AND THE DERIVED DOSE DATA

Quality Factor	Based on:
QF1	Percentage of monitoring periods with a reported numerical value, including zero and 'less than minimum detectable or reported dose' [1]
QF2	Percentage of reported over-apron numerical values that were NOT zero
QF3	Percentage of reported under-apron numerical values that were NOT zero
QF4	Coefficient of variation of reported over-apron values
QF5	Coefficient of variation of reported under-apron values
QF6	Percentage of calculated effective dose values that were NOT 'zero'
QF7	Coefficient of variation of calculated effective dose values

[1] Over-apron results were used if available, otherwise under-apron or deep dose results were used.

TABLE 34. ANALYSIS OF THE QUALITY OF THE REPORTED DOSES, D, PER PARTICIPATING PHYSICIAN FOR THE YEAR

	Mean	Min	Q1	Median	Q3	Max	No. of physicians
Percentage of monitoring periods in the year where $D \geq 0$, QF1 per physician	81.7	0	75	100	100	100	251
Percentage of reported over apron doses[1] that were not zero in the year, QF2 per physician	76.9	0	67	100	100	100	95
Percentage of reported under apron doses[1] that were not zero in the year, QF3 per physician	53.1	0	8	50	100	100	207
Coefficient of variation of reported over apron doses in the year, QF4 per physician	82.7	0.4	41	72	109	255	79
Coefficient of variation of reported under apron doses in the year, QF5 per physician	123.1	0	53	102	173	346	151

[1] Only reported doses with a numerical value ≥ 0 were considered in the denominator.

TABLE 35. ANALYSIS OF THE QUALITY OF THE REPORTED DOSES, D, PER PARTICIPATING IC FACILITY FOR THE YEAR

	Mean	Min	Median	Max	No. of IC facilities
Percentage of monitoring periods in the year where $D \geq 0$, QF1 per facility	81.9	18	90	100	22
Percentage of reported over apron doses[1] that were not zero in the year, QF2 per facility	72.0	17	75	100	9
Percentage of reported under apron doses[1] that were not zero in the year, QF3 per facility	57.9	4	56	100	18
Coefficient of variation of reported over apron doses in the year, QF4 per facility	95.0	37	81	249	9
Coefficient of variation of reported under apron doses in the year, QF5 per facility	127.6	21	104	346	18

[1] Only reported doses with a numerical value ≥ 0 were considered in the denominator.

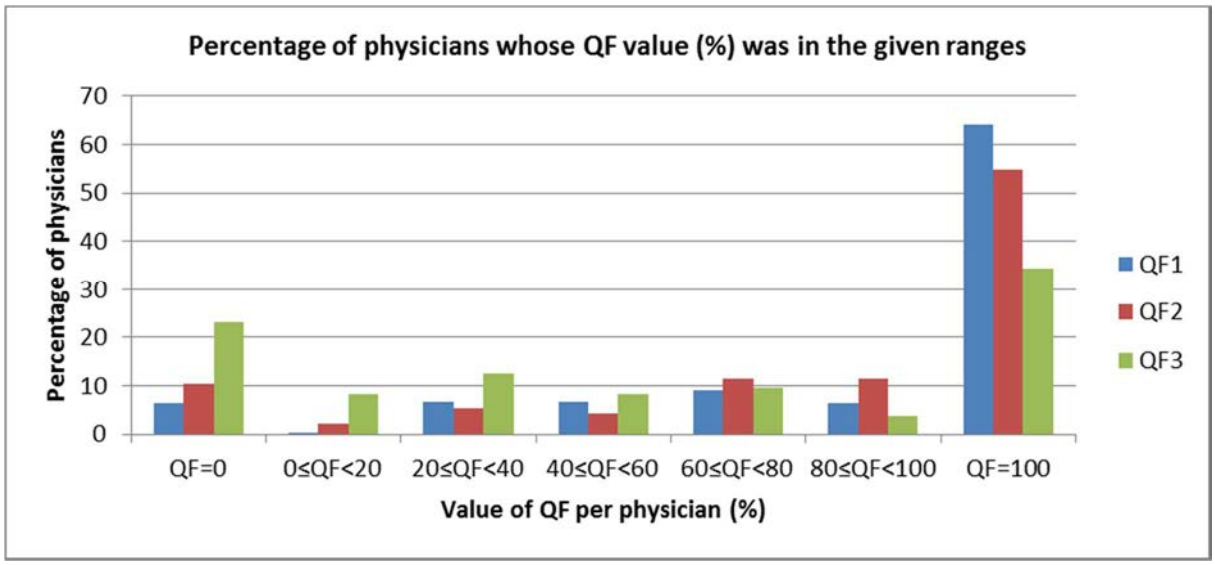

FIG. 16. Distribution of the values of the Quality Factors (QF1, QF2, QF3) derived for each physician from the monitoring period data for the physicians.

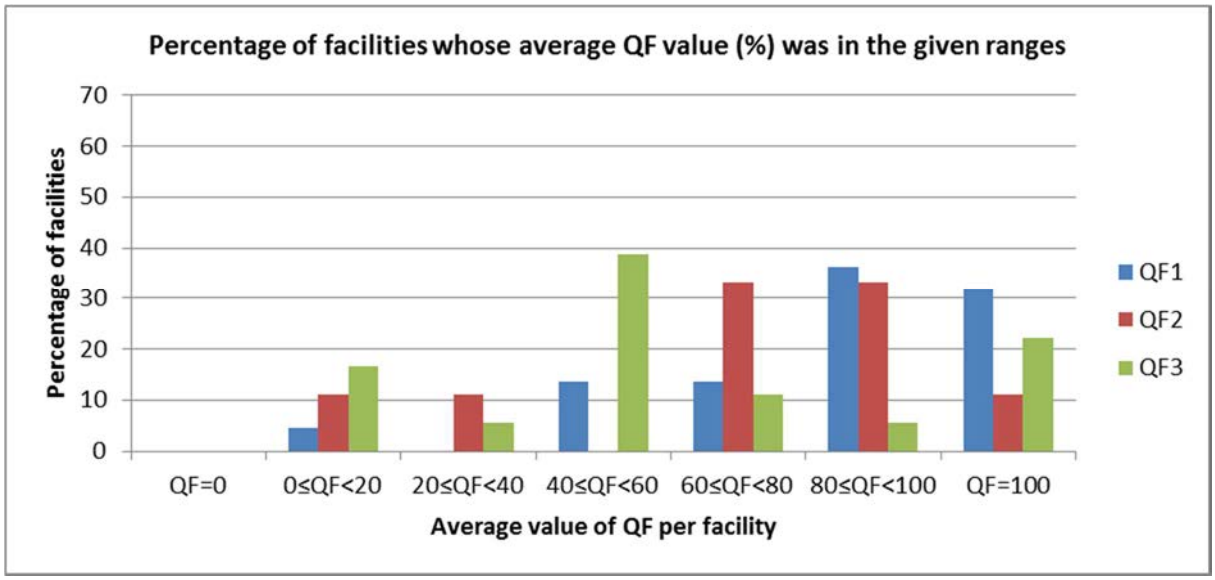

FIG. 17. Distribution of the average values of the Quality Factors (QF1, QF2, QF3) derived for each IC facility from the monitoring period data for the physicians in that facility.

II.5. ESTIMATES OF DOSE METRICS – PHYSICIANS (FOR REPORTED DOSES ≥ 0)

TABLE 36. OVER-APRON DOSES PER PROCEDURE FOR PHYSICIANS

	Over-apron dose[1] per procedure (μSv/procedure)							No. of physicians
	Mean	SD[2]	Min	Q1[3]	Median	Q3[4]	Max	
All interventional cardiologists	39.7	80.4	0	8.8	24.4	41.4	700	135
All electrophysiologists	34.7	30.3	0	9.4	28.6	57.7	102	27
Qualified interventional cardiologists only	30.3	28.4	0	9.0	26.8	40.8	150	94
Trainee interventional cardiologists only	61.1	138	0	3.5	21.1	41.5	700	41

[1] Over-apron dose means the reported $H_p(10)$ from a dosimeter placed above the protective apron, normally at collar level.
[2, 3, 4] SD means standard deviation, Q1 means first quartile, and Q3 means third quartile.

TABLE 37. UNDER-APRON DOSES PER PROCEDURE FOR PHYSICIANS

	Under-apron dose[1] per procedure (μSv/procedure)							No. of physicians
	Mean	SD[2]	Min	Q1[3]	Median	Q3[4]	Max	
All interventional cardiologists	11.4	29.6	0	0.2	2.6	7.7	230	113
All electrophysiologists	1.1	1.6	0	0	0.3	1.7	5.5	20
Qualified interventional cardiologists only	10.8	24.4	0	0.3	2.8	7.7	159	92
Trainee interventional cardiologists only	13.9	49.9	0	0	0.4	2.9	230	21

[1] Under-apron dose means the reported $H_p(10)$ from a dosimeter placed under the protective apron, normally at chest or waist level.
[2, 3, 4] SD means standard deviation, Q1 means first quartile, and Q3 means third quartile.

TABLE 38. EFFECTIVE DOSES PER PROCEDURE FOR PHYSICIANS

	Effective dose[1] per procedure (μSv/procedure)							No. of physicians
	Mean	SD[2]	Min	Q1[3]	Median	Q3[4]	Max	
All interventional cardiologists	10.6	35.8	0	0.1	2.3	5.5	419	255
All electrophysiologists	3.0	3.5	0	0.2	2.0	4.6	17.5	45
Qualified interventional cardiologists only	12.5	31.7	0	1.2	3.1	8.4	261	148
Trainee interventional cardiologists only	16.3	65.6	0	1.0	2.7	4.7	419	41

[1] Effective dose has been calculated from the reported dosimeter values using the algorithm: If 2 dosimeters, ED = 0.075OA + 1.64UA; if one dosimeter, ED = 0.075OA or ED = 1.64UA, depending on which dosimeter was worn, where ED = effective dose, OA = reported $H_p(10)$ from a dosimeter placed over the protective apron, and UA = reported $H_p(10)$ from a dosimeter placed under the protective apron. See also reference [6].
[2, 3, 4] SD means standard deviation, Q1 means first quartile, and Q3 means third quartile.

TABLE 39. LENS DOSES PER PROCEDURE FOR PHYSICIANS

	Lens dose[1] per procedure (µSv/procedure)							No. of physicians
	Mean	SD[2]	Min	Q1[3]	Median	Q3[4]	Max	
All interventional cardiologists	31.7	70.4	0	0	16.1	37.1	700	201
All electrophysiologists	44.8	111	0	1.4	19.2	43.7	680	37
Qualified interventional cardiologists only	30.3	28.3	0	9.1	25.9	40.8	149	94
Trainee interventional cardiologists only	61.1	138	0	3.5	21.1	41.5	700	41

[1] Lens dose means the reported value from a dosimeter specifically placed to measure lens dose or the reported over apron dose.
[2, 3, 4] SD means standard deviation, Q1 means first quartile, and Q3 means third quartile.

TABLE 40. HAND DOSES PER PROCEDURE FOR PHYSICIANS

	Hand dose[1] per procedure (µSv/procedure)							No. of physicians
	Mean	SD[2]	Min	Q1[3]	Median	Q3[4]	Max	
All interventional cardiologists	31.7	70.4	0	0	16.1	37.1	700	201

[1] Hand dose means the reported value from a dosimeter specifically placed to measure hand dose.
[2, 3, 4] SD means standard deviation, Q1 means first quartile, and Q3 means third quartile.

II.6. ESTIMATES OF DOSE METRICS – NON-PHYSICIAN PERSONNEL (FOR REPORTED DOSES ≥ ZERO)

TABLE 41. OVER-APRON DOSES PER PROCEDURE FOR NON-PHYSICIAN PERSONNEL

	Over-apron dose[1] per procedure (µSv/procedure)							No. of persons
	Mean	SD[2]	Min	Q1[3]	Median	Q3[4]	Max	
Nurses[5]	9.9	12.2	0	0	1.5	21.6	31.7	20
Technicians[6]	7.2	5.8	0	3.1	7.0	10.0	24.6	31

[1] Over apron dose means the reported $H_p(10)$ from a dosimeter placed above the protective apron, normally at collar level.
[2, 3, 4] SD means standard deviation, Q1 means first quartile, and Q3 means third quartile.
[5] If an additional single extreme 'outlier' is included, the mean, standard deviation, minimum, 1st quartile, median, 3rd quartile and maximum become 77.3, 309, 0, 0, 1.7, 24.5, 1425, respectively.
[6] The term technician here covers technicians, technologists and radiographers.

TABLE 42. UNDER-APRON DOSES PER PROCEDURE FOR NON-PHYSICIAN PERSONNEL

	Under-apron dose[1] per procedure (μSv/procedure)							No. of persons
	Mean	SD[2]	Min	Q1[3]	Median	Q3[4]	Max	
Nurses	0.3	0.7	0	0	0.1	0.2	4.0	36
Technicians[5]	0.6	0.5	0	0	0.2	0.6	1.5	13

[1] Under apron dose means the reported $H_p(10)$ from a dosimeter placed under the protective apron, normally at chest or waist level.
[2, 3, 4] SD means standard deviation, Q1 means first quartile, and Q3 means third quartile.
[5] The term technician here covers technicians, technologists and radiographers.

TABLE 43. EFFECTIVE DOSES PER PROCEDURE FOR NON-PHYSICIAN PERSONNEL

	Effective dose[1] per procedure (μSv/procedure)							No. of persons
	Mean	SD[2]	Min	Q1[3]	Median	Q3[4]	Max	
Nurses[5]	0.7	1.2	0	0	0.2	0.6	6.6	46
Technicians[6]	0.7	0.7	0	0	0.5	0.8	3.0	41

[1] Effective dose has been calculated from the reported dosimeter values using the algorithm: If 2 dosimeters, ED = 0.075OA + 1.64UA; if one dosimeter, ED = 0.075OA or ED = 1.64UA, depending on which dosimeter was worn, where ED = effective dose, OA = reported $H_p(10)$ from a dosimeter placed over the protective apron, and UA = reported $H_p(10)$ from a dosimeter placed under the protective apron. See also reference [6].
[2, 3, 4] SD means standard deviation, Q1 means first quartile, and Q3 means third quartile.
[5] If an additional single extreme 'outlier' is included, the mean, standard deviation, minimum, 1st quartile, median, 3rd quartile and maximum become 2.9, 15.5, 0, 0, 0.2, 0.7, 107, respectively.
[6] The term technician here covers technicians, technologists and radiographers.

TABLE 44. LENS DOSES PER PROCEDURE FOR NON-PHYSICIAN PERSONNEL

	Lens dose[1] per procedure (μSv/procedure)							No. of persons
	Mean	SD[2]	Min	Q1[3]	Median	Q3[4]	Max	
Nurses[5]	9.9	12.2	0	0	1.5	21.6	31.7	20
Technicians	7.2	5.8	0	3.1	7.0	10.0	24.6	31
Unspecified[6], IC	5.3	8.3	0	0.2	2.9	5.1	40.0	58
Unspecified[7], EP	0.6	0.6	0	0.1	0.2	0.8	1.9	11

[1] Lens dose means the reported value from a dosimeter specifically placed to measure lens dose or the reported over-apron dose. For the persons in this table, all results were based on the over-apron dose.
[2, 3, 4] SD means standard deviation, Q1 means first quartile, and Q3 means third quartile.
[5] If an additional single extreme 'outlier' is included, the mean, standard deviation, minimum, 1st quartile, median, 3rd quartile and maximum become 77.3, 309, 0, 0, 1.7, 24.5, 1425, respectively.
[6, 7] Unspecified means that it was not stated whether the person was a nurse or technician.

II.7. OVER APRON DOSE TO UNDER APRON DOSE RATIOS

TABLE 45. RATIOS OF OVER-APRON DOSE TO UNDER-APRON DOSE, ANALYSED PER MONITORING PERIOD WHERE THERE WERE REPORTED VALUES FOR BOTH DOSIMETERS AND THE UNDER-APRON DOSE WAS NOT ZERO

	Ratio of over-apron dose to under-apron dose							Number of monitoring periods with data
	Mean	SD[1]	Minimum	Q1[2]	Median	Q3[3]	Maximum	
All Physicians	14.5	19.1	0	2.0	7.5	19.2	129.2	106
Interventional cardiologists	12.7	18.7	0	1.8	6.0	14.9	129.2	90
Electrophysiologists	24.5	18.8	0.05	12.4	19.7	28.1	68.3	16

[1, 2, 3] SD means standard deviation, Q1 means first quartile, and Q3 means third quartile.
Note. These data come from only four facilities, and one of those had only one participating physician.

TABLE 46. RATIOS OF OVER-APRON DOSE TO UNDER-APRON DOSE, ANALYSED PER PHYSICIAN FOR A YEAR, WHERE THERE WERE REPORTED VALUES FOR BOTH DOSIMETERS AND THE UNDER-APRON DOSE WAS NOT ZERO

	Ratio of over-apron dose to under-apron dose							Number of physicians with data
	Mean	SD[1]	Minimum	Q1[2]	Median	Q3[3]	Maximum	
All Physicians	10.3	13.3	0	1.7	4.7	14.2	56.0	40
Interventional cardiologists	9.7	13.7	0	1.5	2.5	11	56.0	35
Electrophysiologists	14.4	9.4	1.8	9.0	15.2	20.2	26.0	5

[1, 2, 3] SD means standard deviation, Q1 means first quartile, and Q3 means third quartile.
Note. These data come from only four facilities, and one of those had only one participating physician.

II.8. FILTERING THE RAW DATA TO IMPROVE ITS QUALITY

TABLE 47. INFLUENCE ON THE ESTIMATES OF THE OVER-APRON DOSE METRIC (OCCUPATIONAL DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE 33) TO FILTER THE RAW DATA

Quality filter applied	Over-apron dose per procedure (μSv/proc)		Number of data
	Mean	2 × Standard error	
No filter – raw data	22.0	4.9	63
QF1 > 75	27.0	5.6	46
QF1 = 100	28.0	6.3	40
QF2 > 50	23.1	5.2	56
QF2 > 75	22.6	5.4	53
QF2 = 100	26.3	6.8	31
QF4 < 150	28.1	5.2	46
QF4 < 100	28.4	5.7	37
QF4 < 50	33.5	9.3	18
QF1 = 100 & QF2 = 100	30.0	8.5	23
QF1 = 100 & QF4 < 100	32.0	7.1	27
QF1 = 100 & QF2 = 100 & QF4 < 100	30. 9	8.7	22

TABLE 48. INFLUENCE ON THE ESTIMATES OF THE UNDER-APRON DOSE METRIC (OCCUPATIONAL DOSE PER PROCEDURE) FOR INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE 33) TO FILTER THE RAW DATA

Quality filter applied	Under-apron dose per procedure (μSv/proc)		Number of data
	Mean	2 × Standard error	
No filter – raw data	10.8	4.8	92
QF1 > 75	11.8	5.3	83
QF1 = 100	13.6	6.2	69
QF3 > 50	13.2	6.2	68
QF3 > 75	15.8	7.8	53
QF3 = 100	18.5	9.4	43
QF5 < 150	14.2	6.9	61
QF5 < 100	13.2	6.4	41
QF5 < 50	15.3	9.8	22
QF1 = 100 & QF3 = 100	21.5	11.0	36
QF1 = 100 & QF5 < 100	14.9	7.4	35
QF1 = 100 & QF3 = 100 & QF5 < 100	16.5	8.7	29

TABLE 49. INFLUENCE ON THE ESTIMATES OF THE EFFECTIVE DOSE METRIC (OCCUPATIONAL EFFECTIVE DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE 33) TO FILTER THE RAW DATA

Quality filter applied	Effective dose per procedure (μSv/proc)		Number of data
	Mean	2 × Standard error	
No filter – raw data	14.8	6.3	117
QF1 > 75	17.9	7.6	95
QF1 = 100	20.8	9.1	78
QF6 > 50	15.6	6.9	104
QF6 > 75	16.7	7.8	91
QF6 = 100	21.9	10.8	64
QF7 < 150	17.9	8.2	86
QF7 < 100	15.4	7.3	62
QF7 < 50	18.6	11.5	32
QF1 = 100 & QF6 = 100	27.2	13.5	50
QF1 = 100 & QF7 < 100	18.9	9.0	49
QF1 = 100 & QF6 = 100 & QF7 < 100	21.6	11.1	39

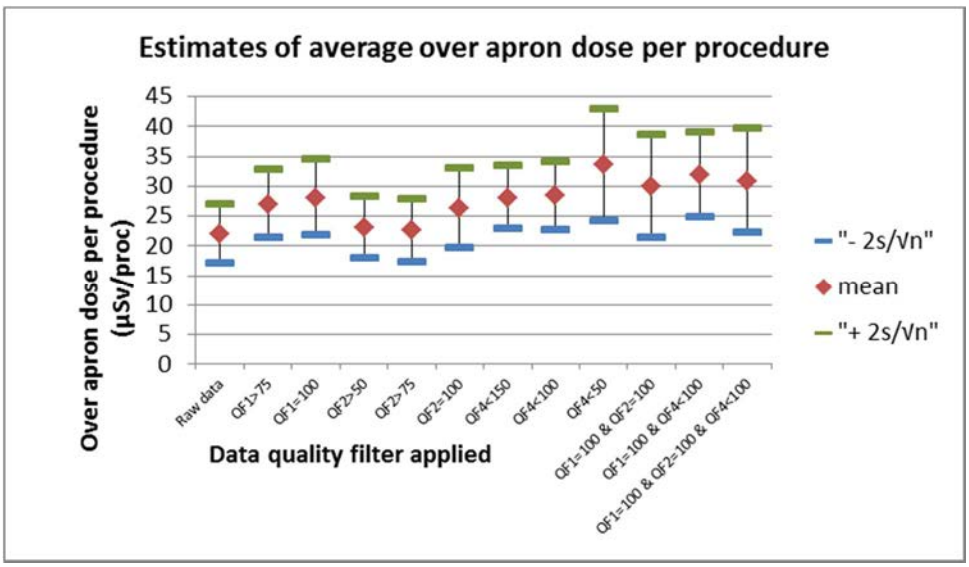

FIG. 18. Estimates of the average over apron dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied.

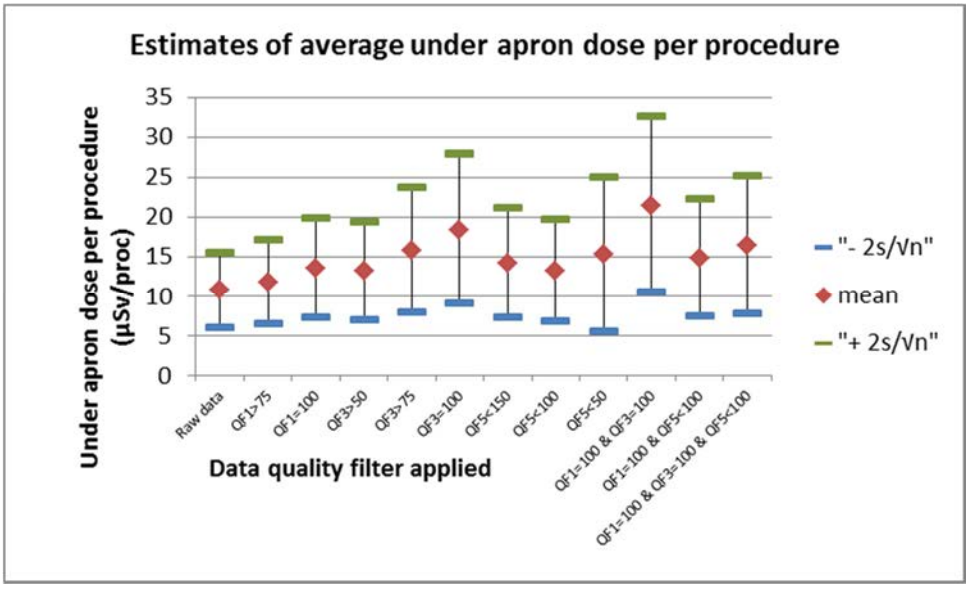

FIG. 19. Estimates of the average under apron dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied.

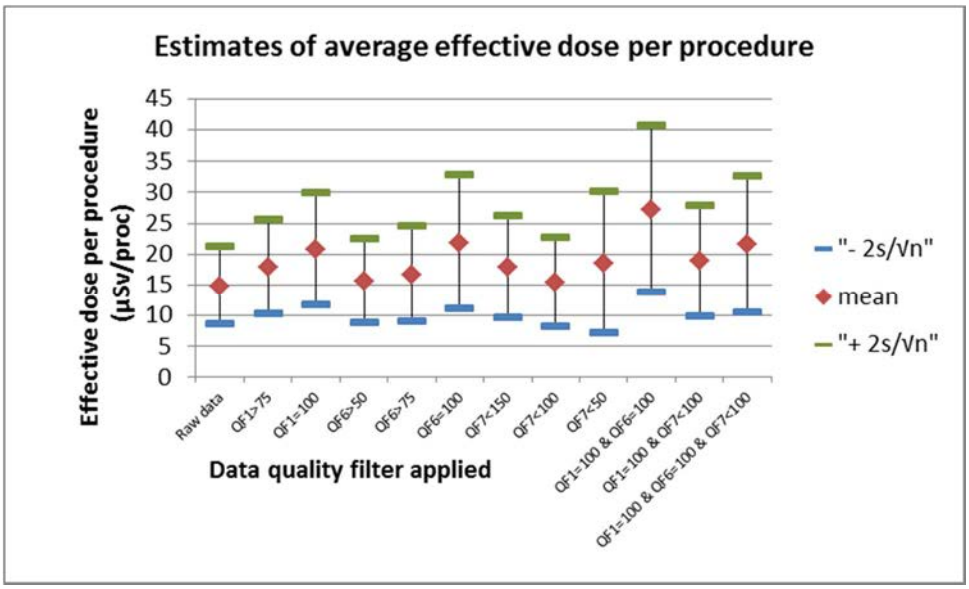

FIG. 20. Estimates of the average occupational effective dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied.

TABLE 50. INFLUENCE ON THE ESTIMATES OF THE OVER-APRON DOSE METRIC (OCCUPATIONAL DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE 33) TO FILTER THE RAW DATA, BUT EXCLUDING DATA FOR ANNUAL WORKLOADS OF FEWER THAN 50 PROCEDURES

Quality filter applied	Over-apron dose per procedure (μSv/proc)		Number of data
	Mean	2 × Standard error	
No filter – raw data	23.2	5.2	57
QF1 > 75	28.2	6.0	42
QF1 = 100	29.0	6.7	37
QF2 > 50	24.3	5.4	51
QF2 > 75	23.5	5.5	49
QF2 = 100	26.7	7.1	29
QF4 < 150	28.8	5.4	43
QF4 < 100	28.8	5.9	35
QF4 < 50	33.5	9.3	18
QF1 = 100 & QF2 = 100	30.8	9.0	21
QF1 = 100 & QF4 < 100	32.8	7.4	25
QF1 = 100 & QF2 = 100 & QF4 < 100	31.9	9.2	20

TABLE 51. INFLUENCE ON THE ESTIMATES OF THE UNDER-APRON DOSE METRIC (OCCUPATIONAL DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE 33) TO FILTER THE RAW DATA, BUT EXCLUDING DATA FOR ANNUAL WORKLOADS OF FEWER THAN 50 PROCEDURES

Quality filter applied	Under-apron dose per procedure (μSv/proc)		Number of data
	Mean	2 × Standard error	
No filter – raw data	8.9	3.7	85
QF1 > 75	9.6	4.0	77
QF1 = 100	11.0	4.7	64
QF3 > 50	10.6	4.6	64
QF3 > 75	12.6	5.7	50
QF3 = 100	14.2	6.7	41
QF5 < 150	11.3	5.0	58
QF5 < 100	12.3	6.3	40
QF5 < 50	13.6	9.6	21
QF1 = 100 & QF3 = 100	16.6	7.9	34
QF1 = 100 & QF5 < 100	13.8	7.2	34
QF1 = 100 & QF3 = 100 & QF5 < 100	15.2	8.7	28

TABLE 52. INFLUENCE ON THE ESTIMATES OF THE EFFECTIVE DOSE METRIC (OCCUPATIONAL DOSE PER PROCEDURE) FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS FROM THE USE OF QUALITY FACTORS (SEE TABLE 33) TO FILTER THE RAW DATA, EXCLUDING DATA FOR ANNUAL WORKLOADS OF FEWER THAN 50 PROCEDURES

Quality filter applied	Effective dose per procedure (μSv/proc)		Number of data
	Mean	2 × Standard error	
No filter – raw data	12.2	4.8	109
QF1 > 75	14.6	5.7	89
QF1 = 100	16.9	6.8	73
QF6 > 50	12.7	5.1	97
QF6 > 75	13.5	5.8	85
QF6 = 100	17.0	7.9	60
QF7 < 150	14.3	5.9	83
QF7 < 100	14.3	7.0	61
QF7 < 50	16.5	11.0	31
QF1 = 100 & QF6 = 100	21.3	10.0	46
QF1 = 100 & QF7 < 100	17.5	8.7	48
QF1 = 100 & QF6 = 100 & QF7 < 100	19.9	10.8	38

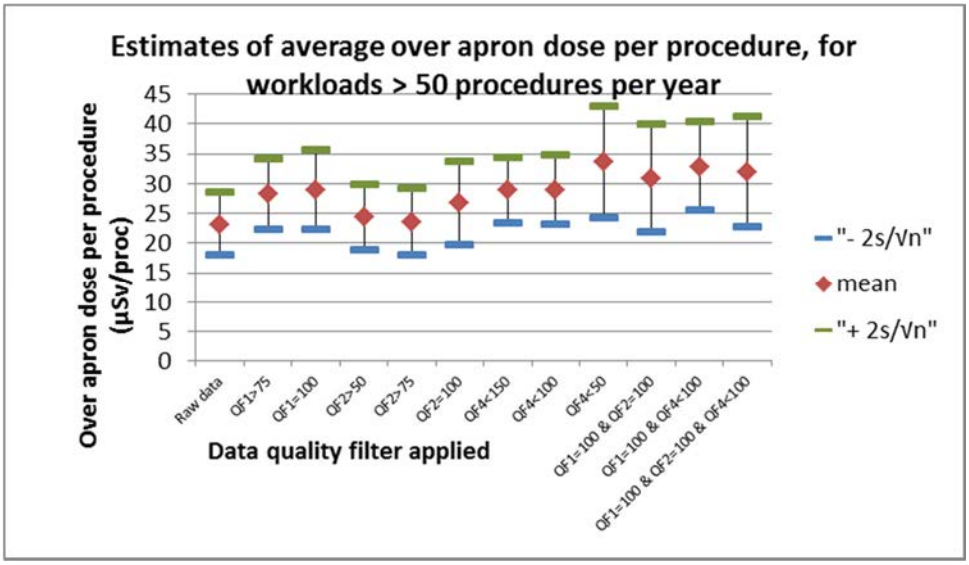

FIG. 21. Estimates of the average over-apron dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied, excluding data for annual workloads of fewer than 50 procedures.

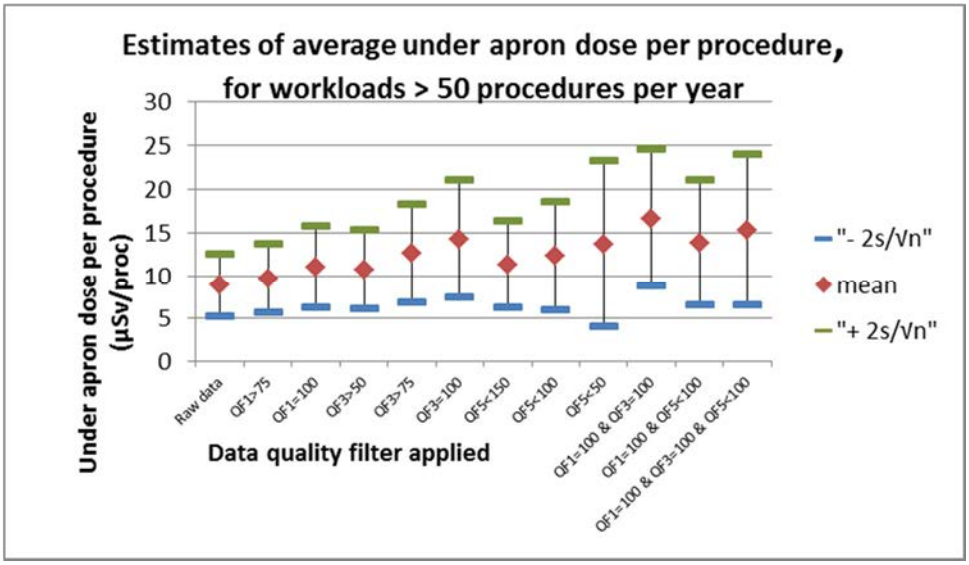

FIG. 22. Estimates of the average under apron dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied, excluding data for annual workloads of fewer than 50 procedures.

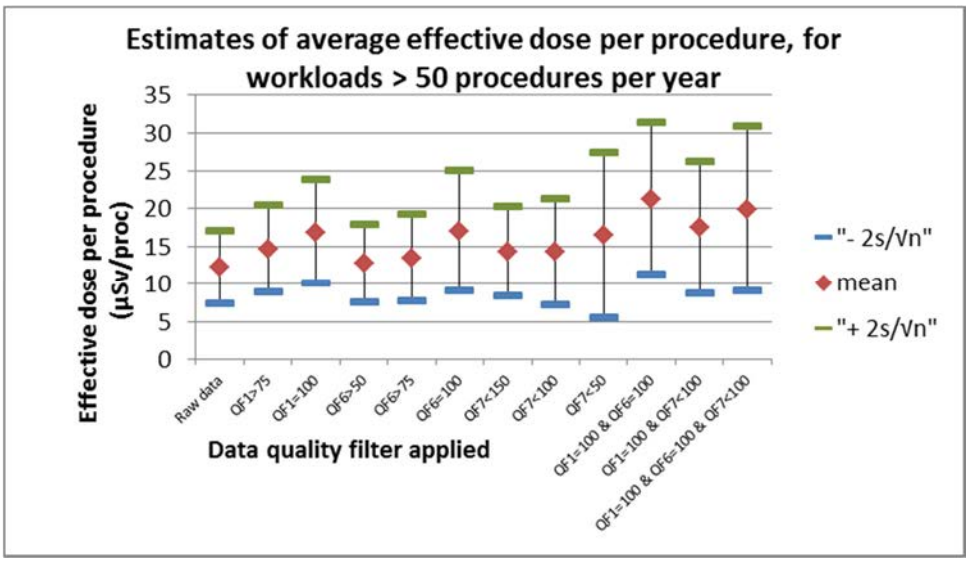

FIG. 23. Estimates of the average occupational effective dose per procedure for qualified interventional cardiologists as a function of the data quality filter applied, excluding data for annual workloads of fewer than 50 procedures.

TABLE 53. INFLUENCE ON THE COEFFICIENT OF CORRELATION BETWEEN THE ANNUAL OVER-APRON DOSE AND THE ANNUAL NUMBER OF PROCEDURES FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE 33) TO FILTER THE RAW DATA

Quality filter applied	All workloads		Only workloads > 50 procedures per year	
	No. of data	Coefficient of correlation[1], r	No. of data	Coefficient of correlation[1], r
No filter – raw data	63	0.75	57	0.73
QF1 > 75	46	0.81	42	0.80
QF1 = 100	40	0.87	37	0.86
QF2 > 50	55	0.76	50	0.74
QF2 = 100	31	0.71	29	0.69
QF4 < 150	46	0.72	43	0.70
QF4 < 100	37	0.73	35	0.71
QF4 < 50	18	0.83	18	0.83
QF1 = 100 & QF2 = 100	23	0.88	21	0.87
QF1 = 100 & QF4 < 100	27	0.88	25	0.87
QF1 = 100 & QF2 = 100 & QF4 < 100	22	0.88	20	0.87

[1] Pearson product-moment correlation coefficient.

TABLE 54. INFLUENCE ON THE COEFFICIENT OF CORRELATION BETWEEN THE ANNUAL UNDER APRON DOSE AND THE ANNUAL NUMBER OF PROCEDURES FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE 33) TO FILTER THE RAW DATA

Quality filter applied	All workloads		Only workloads > 50 procedures per year	
	No. of data	Coefficient of correlation[1], r	No. of data	Coefficient of correlation[1], r
No filter – raw data	92	0.10	85	0.05
QF1 > 75	83	0.08	77	0.03
QF1 = 100	69	0.14	64	0.10
QF3 > 50	58	0.08	55	0.05
QF3 = 100	43	0.02	41	-0.01
QF5 < 150	61	0.09	58	0.06
QF5 < 100	41	0.03	40	0.01
QF5 < 50	22	0.05	21	0.03
QF1 = 100 & QF3 = 100	36	0.01	34	-0.03
QF1 = 100 & QF5 < 100	35	0.01	34	-0.01
QF1 = 100 & QF3 = 100 & QF5 < 100	29	0.03	28	0.01

[1] Pearson product-moment correlation coefficient.

TABLE 55. INFLUENCE ON THE COEFFICIENT OF CORRELATION BETWEEN THE ANNUAL OCCUPATIONAL EFFECTIVE DOSE AND THE ANNUAL NUMBER OF PROCEDURES FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, FROM THE USE OF QUALITY FACTORS (SEE TABLE33) TO FILTER THE RAW DATA

Quality filter applied	**All workloads**		**Only workloads > 50 procedures per year**	
	No. of data	**Coefficient of correlation[1], r**	**No. of data**	**Coefficient of correlation[1], r**
No filter – raw data	117	0.11	109	0.06
QF1 > 75	95	0.05	89	0.01
QF1 = 100	78	0.12	73	0.08
QF6 > 50	97	0.12	91	0.08
QF6 = 100	64	0.05	60	0.01
QF7 < 150	86	0.03	83	0.02
QF7 < 100	62	0.00	61	-0.01
QF7 < 50	32	-0.06	31	-0.08
QF1 = 100 & QF6 = 100	50	0.09	46	0.04
QF1 = 100 & QF7 < 100	49	0.04	48	0.03
QF1 = 100 & QF6 = 100 & QF7 < 100	39	0.04	38	0.03

[1] Pearson product-moment correlation coefficient.

II.9. BENCHMARKING THE PERFORMANCE OF QUALIFIED INTERVENTIONAL CARDIOLOGISTS IN IC FACILITIES

TABLE 56. MEAN OCCUPATIONAL EFFECTIVE DOSE PER PROCEDURE FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS, AVERAGED PER IC FACILITY

IC Facility	**Raw data**		**Filtered data – QF6 > 75 and QF7 < 150**	
	No. of physicians	Mean ED[1] per procedure (μSv/procedure)	No. of physicians	Mean ED[1] per procedure (μSv/procedure)
A	5	1.3	2	3.2
B	10	0.9	4	1.9
C	3	4.0	2	6.0
D	9	17.8	3	2.5
E	13	6.8	9	4.8
F	5	10.4	5	10.4
G	14	75.8	13	80.3
H	3	2.1	3	2.1
I	5	9.2	5	9.2
J	6	1.4	6	1.4
K	6	4.2	5	4.3
L	4	3.3	2	6.7
M	4	3.8	0	-
N	4	20.9	4	20.9
O	8	1.5	0	-
P	7	1.0	2	1.2
Q	1	2.4	0	-
R	6	17.2	3	17.7
S	1	2.5	0	-
T	3	5.8	0	-

[1] ED means effective dose.

TABLE 57. ESTIMATES OF MEAN OCCUPATIONAL EFFECTIVE DOSE PER PROCEDURE FOR QUALIFIED INTERVENTIONAL CARDIOLOGISTS DIVIDED INTO TWO GROUPS BASED ON THEIR REPORTED ANNUAL WORKLOAD – THOSE WHO PERFORMED FEWER THAN 150 PROCEDURES IN THE REPORTED YEAR AND THOSE WHO PERFORMED 150 PROCEDURES OR MORE

Reported number of procedures performed	Number of qualified interventional cardiologists	Mean ED[1] per procedure (μSv/procedure)	2 × Standard Error
< 150	44	27.1	15.8
≥ 150	93	5.65	1.6

[1] ED means effective dose.

APPENDIX III. RECOMMENDATIONS OF THE WORKING GROUP ON INTERVENTIONAL CARDIOLOGY ON OCCUPATIONAL DOSES TO THE LENS OF THE EYE IN INTERVENTIONAL CARDIOLOGY

The International Commission on Radiological Protection (ICRP) published in April 2011 a statement that for the lens of the eye the threshold for tissue reactions was now considered to be 0.5 Gy. As a result ICRP recommended a new occupational dose limit for the lens of the eye of 20 mSv in a year. This recommendation was incorporated into the interim version of the International Basic Safety Standards of the IAEA, published Nov 2011.

The new lower limit has important implications for some areas of occupational exposure, including interventional cardiology, emphasizing the need for optimization of protection measures with respect to the lens of the eye.

The nature of interventional cardiology is that if no protective measures for the eyes are used in an interventional cardiology laboratory, personnel with a typical workload would receive doses to the lens of the eye that would greatly exceed the dose limit, and over time could result in lens opacities.

Conversely, if the interventional cardiology equipment is performing correctly, procedure protocols have been optimized and protective tools for the eyes are being used, then the dose to the lens of the eye would be less than the dose limit, and likely to be a few mSv per year for a typical workload.

Results from the ISEMIR surveys (see Sections 3 and 4) suggest that the use of protective tools and personal dosimeters are uneven, the quality of occupational dose monitoring is poor, and as a consequence knowledge about actual doses is limited. This has implications for the professionals, hospital or clinic management, and regulatory bodies.

Therefore the WGIC of ISEMIR recommends:

Training in radiation protection for all interventional cardiology personnel should include methods for reducing doses to the lens of the eyes, with practical exercises or demonstrations. Active dosimeters should be used in training.

Interventional cardiology professionals working close to the patient must use a ceiling suspended protective screen, positioned appropriately. If the use of such screens is not feasible with a given procedure, lead glasses with side shields must be worn.

Protective measures for interventional cardiology professionals working more distant from the irradiated volume of the patient should be specified by the local expert in radiation protection (e.g. radiation protection officer, medical physicist).

Interventional cardiology professionals must always wear their personal dosimeters, following their local rules.

Hospital management must perform continual reviews of personnel occupational eye doses.

Personal dosimetry monitoring protocols must include assessment of the dose to the lens of the eye.

Elements of a monitoring protocol should include the following:

The use of double dosimetry (over-apron at neck level and under-apron at chest/waist level);

The use of ambient dosimeters (such as at the C-arm) in identifying the lack of compliance in wearing personal dosimeters and to help to estimate occupational doses when personal dosimeters have not been used;

The use of active dosimeters to identify means for improving radiation protection practice.

Improved methodologies to assess lens doses need to be developed, including when lead glasses are worn.

Industry should pursue the development of computational technologies (not requiring dosimeters), with personnel position sensing, to assess personnel doses, including eye doses.

Manufacturers of interventional cardiology equipment should design their systems so that it is possible to provide a second ceiling suspended screen to afford protection for situations where personnel are working on both sides of the table.

National dose registers should include records for lens of the eye dose assessments. Such records should include the occupation and function of the individual to enable identification of areas of concern.

The ISEMIR International database, under development, will be a useful tool for each interventional cardiology facility and regulatory bodies in benchmarking occupational eye doses in interventional cardiology in the future, and participation is recommended.

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