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Research Article

Radiation Awareness and X-Ray Use in Cardiology: An International Independent Web-Based Survey

Andrea Ballatore,[1,2] **Michela Casella**,[3,4] **Francisco Moscoso Costa**,[5] **Marzia Giaccardi**,[6] **Moti Haim**,[7] **Inga Jóna Ingimarsdóttir**,[8,9] **Nathan Mewton**,[10] **Clara Van Ofwegen-Hanekamp**,[11] **Pierre Ollitrault**,[12] **Agnieszka Pawlak**,[13] **Arian Sultan**,[14] **Mariya Tokmakova**,[15] **Christos Varounis**,[16] **Vanessa Weberndörfer**,[17,18] **Filip Zemrak**,[19,20] **and Matteo Anselmino**[1,2]

[1]*Division of Cardiology, Cardiovascular and Thoracic Department, "Città della Salute e della Scienza" Hospital, Turin, Italy*
[2]*Department of Medical Sciences, University of Turin, Turin, Italy*
[3]*Cardiology and Arrhythmology Clinic, University Hospital "Ospedali Riuniti", Ancona, Italy*
[4]*Department of Clinical, Special, and Dental Sciences, Marche Polytechnic University, Ancona, Italy*
[5]*Cardiology Department, Hospital Sta Cruz, Centro Hospitalar Lisboa Ocidental, Lisboa, Portugal*
[6]*Division of Cardiology, Santa Maria Annunziata Hospital, Florence, Italy*
[7]*Cardiology Department, Soroka Medical Center, Ben-Gurion University of the Negev, Beer-Sheva, Israel*
[8]*Department of Cardiology, Landspitali University Hospital, Reykjavik, Iceland*
[9]*Department of Medical Sciences, University of Iceland, Reykjavik, Iceland*
[10]*Heart Failure Department, Clinical Investigation Center Inserm 1407, Cardiovascular Hospital Louis Pradel, Claude Bernard Lyon 1 University, Lyon, France*
[11]*Diakonessenhuis Utrecht, Utrecht, Netherlands*
[12]*University Hospital Centre, Avenue de la Côte de Nacre, Caen 14000, France*
[13]*National Medical Institute of the Ministry of Interior and Administration, Department of Cardiology, Warsaw, Poland*
[14]*University Hospital Cologne, Department of Electrophysiology, Cologne, Germany*
[15]*Medical University of Plovdiv, Cardiology Department, UMHAT Sv Georgi EAD, Plovdiv, Bulgaria*
[16]*Second Department of Cardiology, School of Medicine, University General Hospital, ATTIKON, National and Kapodistrian University of Athens, Athens, Greece*
[17]*Department of Cardiology, Maastricht University Medical Centre+, Maastricht, Netherlands*
[18]*Cardiovascular Research Institute Maastricht (CARIM), Maastricht University, Maastricht, Netherlands*
[19]*Barts Heart Centre, London, UK*
[20]*University College London, London, UK*

Correspondence should be addressed to Matteo Anselmino; matteo.anselmino@unito.it

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Background. Cardiologists are today exposed to a growing dose of ionising radiation in their practice. Radiation awareness and correct management of X-ray use are the cornerstone to comply with the principles of exposure optimization and justification. *Methods and Results*. An investigator-initiated international voluntary-based survey including 28 questions was conducted across 19 European countries. 228 cardiologists participated in the survey. Invasive cardiology subspecialties were the most represented (83.6%). Radiation exposure is the cause of personal protective equipment-related orthopaedic injuries (personally or in co-workers) or anxiety in 68.5% and 62.9% of cases, respectively. 38.4% of participants have encountered difficulties in having their institutions recognizing periods off work for exceeding radiation exposure limit (16.3% usually and 22.1% on rare occasions). Gender was not associated with any difference in the answers. Age older than 40 years old was associated with an increased

knowledge of personal dosimeter data (71.6% vs. 51.3%, $p = 0.008$). Invasive cardiologists more frequently suffer from orthopaedic injuries (73.0% vs. 44.8%, $p = 0.006$) and show greater participation to radioprotection courses (78.4 vs. 27.6%, $p < 0.001$). *Conclusion*. European cardiologists show appropriate awareness of the risks associated with X-ray use in medical practice and of the principles guiding a proper management of radiation hazard. However, there is still room for improvement, and institutions should promote risk education policies, which are the basis for the creation and diffusion of a community consciousness on radiation hazard.

1. Introduction

The detrimental effects of X-rays on health are well known ([1]), and doctors, nurses, and healthcare personnel are today exposed to a growing dose of ionising radiation. The mean cumulative dose exposure for cardiologists working in the cath lab is 2–5 mSv per year ([2]). It has been calculated that the lifetime risk of fatal cancer increases about 0.05 for every 10 mSv of radiation exposure; these values double for the risk of nonfatal cancer ([3]). This implies a risk of 1 cancer within 80 to 200 interventional cardiologists exposed over a 25-year career, which is additional to the current risk of 1 in 3 persons developing cancer over their lifetime. The burden of radiation exposure is not limited to carcinogenicity. X-rays can lead to cataract and be responsible for reproductive disorders and neurodegenerative effects; they are also associated with anxiety and depression ([4, 5]). In addition, the use of the personal protective equipment (PPE, e.g., lead apron and vest) may cause orthopaedic injuries and pain, leading to absence from work ([6]). These effects are evident in all the staff of the electrophysiology (EP) and cath lab: almost 1 in 4 nurses and 1 in 10 technicians reported harmful effects of X-ray exposure ([5]), with a subsequent relevant social and economic impact on both the society and health structures.

Our main objective was to assess the professional radiation exposure awareness and burden through an international survey among European cardiologists.

2. Methods

The investigator-initiated questionnaire was designed to investigate the practical approach to X-ray use as well as theoretical knowledge and familiarity with current normative among European Cardiologists. The survey was initially conceived by two authors (A.B. and M.A.), and subsequently, it was optimized, revised, and approved by the European Heart Academy task force members and all coauthors. The final voluntary survey, including 28 questions and multiple-choice answers, was run on the SurveyMonkey platform (https://www.surveymonkey.com/; Momentive, Waterford, NY, USA) and published on the European Heart Academy Alumni section of European Society of Cardiology website (https://www.escardio.org/Education/Postgraduate-Programmes/Alumni/).

The link to the survey was promoted with the Alumni newsletter (Fall 2022), and all Alumni Task Force members shared the request to European colleagues via personal contact, e-mail, or social media. Requirement to participate in the survey was acceptance to the website privacy policy (see Supplementary). Since all data were completely anonymous and did not involve patients but European cardiologists on a voluntary basis (not recruited), Ethics Committee approval was not required.

Supplementary Table S1 reports the complete list of questions. The survey was published online from October 2022 to December 2022.

2.1. Statistical Analysis. Continuous variables are reported as the mean and standard deviation (SD), whereas categorical variables are reported as the number of cases and percentage. For stratification in categorical variables, age, years of exposition, and number of procedures as the first practitioner were classified into median and quartiles (IQR). Categorical variables were compared by contingency tables and chi-square test. Continuous variables were compared within strata by ANOVA analysis or *t*-test. Three prespecified subgroup analyses were systematically performed: gender (male vs. female), age (≤40 vs. >40 years old), and current cardiology subspecialty (noninvasive, i.e., clinical cardiology or cardiac imaging, vs. invasive, i.e., electrophysiology or interventional cardiology). All tests of significance were two tailed, and a $p < 0.05$ was considered statistically significant. Analysis was performed using R V.4.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

A total of 228 cardiologists from 19 countries participated in the survey (Figure 1) from 21st October 2022 to 27th December 2022. As illustrated in Figure 1, Italy was the most represented country (41.0%), followed by Israel (16.9%) and Germany (11.2%). Table 1 reports the characteristics of the participants. The majority of participants were male (63.5%), and electrophysiology was the most represented subspecialty (70.6%), followed by interventional cardiology (13.0%). The majority of respondents declared performing at least 150 procedures annually (51.1%), and 36.5% declared performing more than 200 procedures per year. The complete detail of the survey answers is available in the Supplementary Materials (Supplementary Table S1).

3.1. Radioprotection Courses and General Knowledge on Radiation Use. Attendance to a radioprotection course, with or without a final exam, was declared as mandatory for clinical practice in the country of origin by 57.3% of respondents. Among all respondents, one third (30.3%) of respondents did not participate in radioprotection courses, and 29.8%

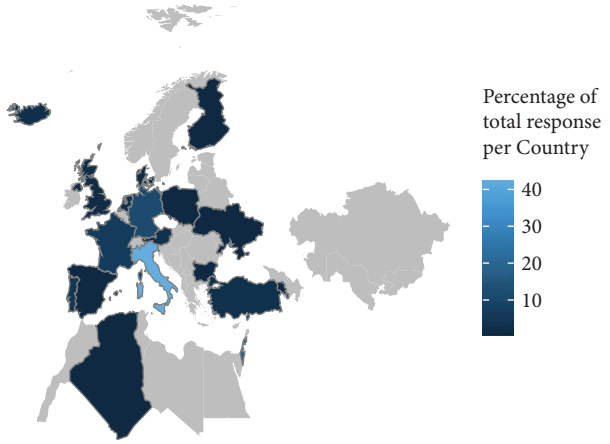

Figure 1: Percentage of participants stratified per ESC National Cardiac Societies' countries.

declared attending to annual radioprotection courses. The main reason for the absence of participation in radioprotection courses was organizational (21.9%) because their institutions do not propose any. The majority of respondents (54.5%) declared being unfamiliar with the European Directive on radiation use (EURATOM 2013/59).

3.2. Practical Aspects on X-Ray Management. Awareness of the identity of the center radioprotection officer was declared by 78.7% of respondents. The majority of participants (62.9%) declared being informed about the data collected by their dosimeter over the year, whereas 8.4% declared not using it, and 15.7% declared a lack of concern regarding dosimeter data. A radiographer available for all the procedures was declared by about half of respondents (52.0%), and the majority of respondents (74.1%) declared that the X-ray machine has been optimized to limit exposure in the majority of cases (22.4% of respondents not knowing this information).

Storage of individual patient-related radiological exposure was declared by 71.3% of respondents. Among all respondents, 49.7% declared using an electroanatomic mapping system for electrophysiology procedures in order to limit radiation exposure. The reasons preventing the use of an electroanatomic mapping system were economic (29.9%), their unavailability (11.4%), or the belief that they are not necessary (9.0% of respondents).

3.3. How Radiation Awareness Affects Clinical Decisions. Concern for patients' radiation exposure was declared as the main element affecting clinical decision in prescribing an imaging exam or an invasive procedure for 18.0% of respondents, whereas 20.2% of respondents declared not being affected by radiation exposure in their decision process. Patient written information about the risks of radiation exposure was declared by 52.2% of respondents. Patient oral information about the risks of radiation exposure was declared by 30.3% of respondents, and 27.5% of respondents declared informing only paediatric patients or women in childbearing age.

3.4. How X-Ray Exposure Personally Affects European Cardiologists. Two-thirds (68.5%) declare to have personally suffered or to know colleagues having suffered from back pain or other orthopaedic conditions due to the use of personal protective equipment; however, a similar percentage of the respondents (62.4%) do not know if these injuries are recognized in their countries as profession related (No: 19.1% and Yes: 18.5%).

Among all respondents, 15.7% usually feel anxious and worried regarding radiation exposure, 47.2% usually do not, and 1.7% believe that radiation exposure risks are overestimated. Conversely, 42.0% of respondents presume that their colleagues underestimate the risk of radiation exposure, and 38.4% have encountered difficulties in having their institutions recognize off work periods for exceeding radiation exposure limit (16.3% usually and 22.1% on rare occasions).

3.5. Specific Knowledge on Radiation Use and Exposure. Half the respondents correctly identified the percentage of incident cancer ([7]) (50%) due to medical radiation exposure and the equivalent dose of chest X-rays for an AF ablation ([8]) (51.7%).

Only one third (34.9%) recognized the use of PPE (lead apron and vest) as significantly associated with orthopaedic injuries.

3.6. Subgroup Analysis. Gender was not associated with any difference in the answers. Age older than 40 years old was associated with an increased knowledge of personal dosimeter data (71.6% vs. 51.3%, $p = 0.008$, Figure 2), with greater participation of the radiographer in all the procedures (58.5% vs. 45.0%, $p = 0.001$) and with a lower portion of respondents believing that the use of electroanatomic mapping systems is not necessary (3.4% vs. 15.8%, $p = 0.009$).

An invasive cardiology subspecialty is associated with greater knowledge of the EURATOM directive (50% vs. 20.7%, $p = 0.007$) and participation to radioprotection courses (78.4 vs. 27.6%, $p < 0.001$). Invasive cardiologists more frequently suffer from orthopaedic injuries (73.0% vs. 44.8%, $p = 0.006$) and show greater awareness of the risk associated with lead PPE (38.4% vs. 14.3%, $p < 0.001$; Figure 3). No statistically significant difference was detected between respondents working in the EP and catheter labs.

4. Discussion

The widespread adoption of invasive procedures in cardiology and subsequently the use of X-rays warrant the diffusion of cultural attention toward comprehensive radiation awareness.

The principal findings of this survey are

(i) European cardiologists show an appropriate level of cognizance on the medical use of ionising radiation

(ii) Invasive subspecialties appear to be associated with an increased awareness of radioprotection topics, regulations, and personal exposure data

Table 1: Principal participants' demographic characteristics (mean ± SD, or number and percentage).

Variable	
Gender, female	65 (36.5%)
Age (years)	43.1 (±9.3)
Current cardiology subspecialty:	
(i) Clinical cardiology	20 (11.3%)
(ii) Cardiac imaging	9 (5.1%)
(iii) Electrophysiology	125 (70.6%)
(iv) Interventional cardiology	23 (13.0%)
EP lab present at the center	174 (97.8%)
Cath lab present at the center	166 (93.3%)
Nuclear medicine service (for cardiovascular imaging) present at the center	126 (70.8%)

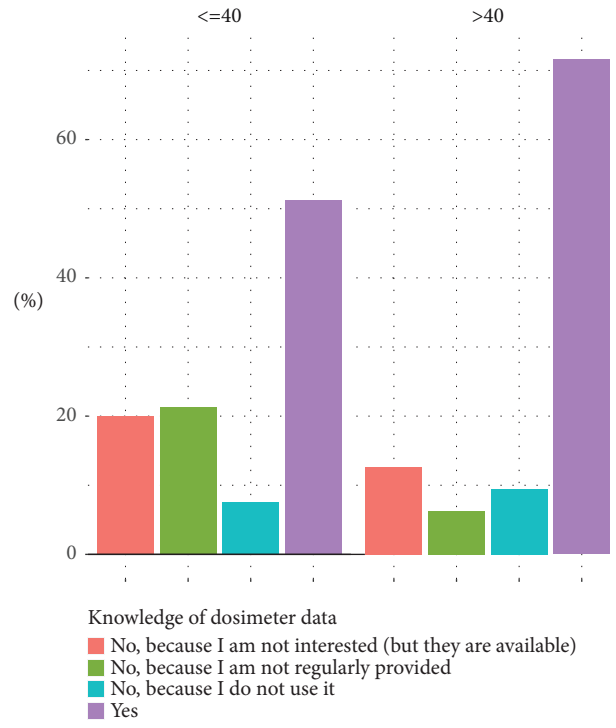

Figure 2: Knowledge of personal annual dosimeter data stratified according to respondents' age (equal or less than 40 years old and above 40 years old).

(iii) A nonmarginal percentage of respondents declare to have difficulties in having recognized periods off work by their institution for exceeding radiation exposure limit

(iv) Almost one in three participants declared not having participated in radioprotection courses

Cardiologists are responsible for up to 40% of patients' exposure to X-rays ([9]) since the increasing incidence of cardiovascular diseases and the adoption of invasive procedures requiring radiation guidance. In recent years, great attention has been focused on the safety issues associated with radiation use in medical sciences and how to prevent them, as suggested by the publication of recent consensus documents ([4, 10, 11]). The diffusion of radioprotection courses, their implementation in regular curricula during cardiologists' formation years, and their requirement to practice are the basis for the creation and diffusion of a community consciousness on radiation hazard. Yet the proportion of European cardiologists who did not participate in radioprotection courses is not negligible. This is of the utmost importance as formation is the basis to shape correct behaviours in daily clinical practice ([12, 13]) such as properly wearing dosimeters, using personal protective equipment, and leading shield and adoption of low dose protocols. In the opinion of this international writing group, radioprotection courses, possibly with a final exam, should be structured and mandatory for all practicing cardiologists; moreover, all electrophysiologists and interventional cardiologists should be familiar with the instruments available in their laboratories and attend both theoretical and practical courses on their specifications.

Interestingly, cardiologists younger than 40 years of age showed a reduced knowledge of personal radiation exposure data and a lower belief in the necessity of electroanatomic mapping systems (EAMS). This may be related to the fact that in the early years of their career, they are more focused on acquiring the necessary skills and less on the risks associated with radiation exposures. The issue of poor radiation awareness within fellows in training is also common in the United States of America and Canada. In a recent survey on 111 interventional cardiology fellows ([14]), only about one in ten (13%) regularly checked their own radiation exposure; one in four (24%) claimed to have received a warning for excessive radiation exposure, of whom four out of five (81%) made changes to their routine to reduce it. These data have improved compared to a previous survey in 2010 ([15]), in which only half of fellows wore a dosimeter and one in five knew its own previous year level of radiation exposure, but they are, nevertheless, far from optimal.

Implementation of EAMS represents the start a new era in contemporary electrophysiology ([16, 17]). EMAS allow to reach for several arrhythmias ([18–20]), similar results compared to the conventional approach by significantly decreasing the lifetime cancer risk ([21, 22]). EMAS permit precise catheter manoeuvrability and localization (with visual tagging), voltage and activation mapping, assessment of conduction velocity, and identification of abnormal electrical activation. These peculiar features, on top of the classical electrophysiological signal-based approach, facilitate arrhythmic circuit and cardiac substrate description,

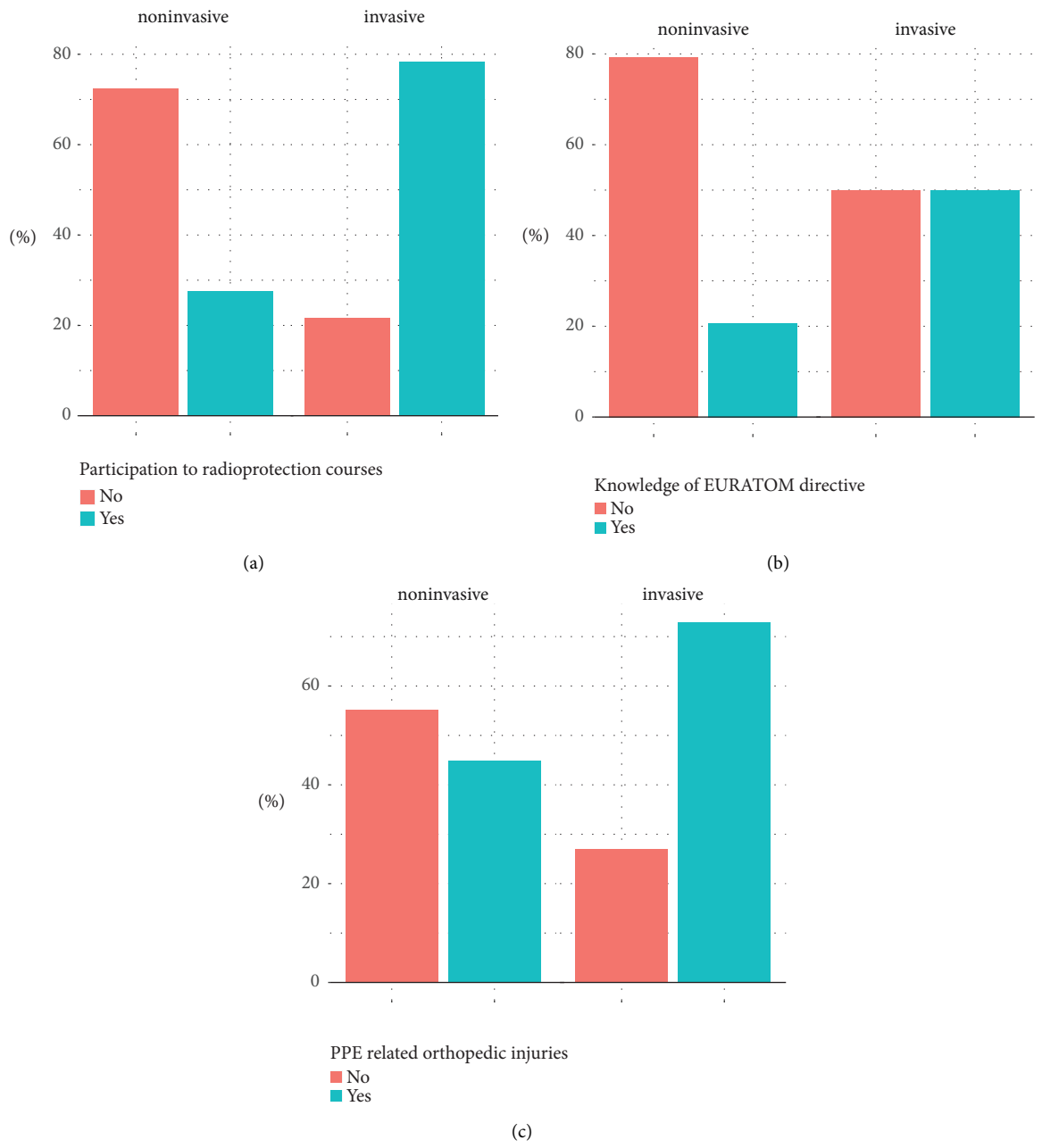

Figure 3: Cardiology subspecialty and participation to radioprotection courses (a), knowledge of EURATOM directive on radioprotection (b), and personal protective equipment (PPE) related orthopaedic injuries (c). (a) For the purpose of this figure and of the analysis reported in the main text, the answers "No, because my Institution does not propose any" and "No, for other reasons (but they are available)" have been merged in "No," and the answers "Yes, at least once a year," "Yes, at least once every three years," and "Yes, at least once in the last five years" have been merged in "Yes."

permitting to achieve highly efficient and safe procedures, limiting the feared side effects of radiation exposure.

In any case, the strategy of dose reduction of a single exam or procedure, based on the ALARA (as low as reasonably achievable) principle, is still equally necessary ([8, 17]) as demonstrated by the fact that in most cases, the concern of patient exposure is not the driving element during prescription.

Finally, on top of practical and technical aspects of radiation management and knowledge, we investigated the effects on personal life: the nonmarginal percentage of cardiologists feeling anxious clearly indicates how X-ray exposure negatively affects psychological well-being; a recent EHRA survey underlined these effects demonstrating that two out of three members of the EP personnel, both women and men, are worried about possible damage to their

reproductive capacity and/or offspring due to ionising radiation ([23]). Once again, proper education is the cornerstone for overcoming these issues as evidenced by the aforementioned EHRA survey according to which 70% of male respondents were concerned about the effects of X-ray exposure on the semen quality, but only 24.5% of them knew the corresponding radiation threshold.

Moreover, the psychological effects may be exacerbated by the perception in almost half the responses that coworkers underestimate the risk of radiation. The latter further reinforces the concept that a collective effort is necessary when approaching the radiation risk. Indeed, we believe that appropriate education on the effects of ionising radiation to all working staff (particularly, but not exclusively, in the EP and cath lab) would create a cooperative and cohesive environment, conscious of the possible risks related to X-rays but soothing the related anxieties.

Overall, there surely is room for improvement; data on the portion of cardiologists still encountering difficulties in having recognized days off work for exceeding radiation limit are striking. Similarly, the main reason for not participating in radioprotection courses is because institutions do not propose any. Notwithstanding, personal responsibilities should not be overlooked: several resources on the radioprotection topic are easily found (commonly for free), and, in addition, mandatory continuous medical education programs (although different in each country) include this topic for all physicians. Finally, all cardiologists who handle in daily practice radiation exposure have the moral responsibility to update and improve their knowledge and competences in this respect. Efforts exerted by the scientific community are encouraging, but further diffusion of the radioprotection culture is needed.

4.1. Limitations. This work presents the following limitations. Despite the inquiries were not directed to specific subspecialists, the majority of respondents are electrophysiologists; differences in the answers according to the respondents' subspecialty are therefore hampered by the heterogeneity of the subgroups. Nevertheless, even though single subspecialties may be underrepresented, the overall cohort of respondents not working in the EP lab is significant, providing, in our opinion, a reliable picture of the general radiation awareness of European cardiologists (in any case, aligned with previously published surveys ([14, 15])). Finally, albeit international, this survey was actively directed only to European cardiologists, from member countries of the European Society of Cardiology; therefore, differences with the level of radiation awareness among cardiologists of other countries (e.g., the United States of America) have not been investigated.

5. Conclusion

European cardiologists show appropriate awareness of the risks associated with X-ray use in medical practice and of the principles guiding a proper management of radiation hazard. Institutions should promote the diffusion of this growing culture, as further risk reduction may be achieved exclusively with an increase in risk awareness.

Data Availability

The data used to support the findings of this study are available from the corresponding author on reasonable request.

Conflicts of Interest

MA is the consultant for Biosense Webster and Boston Scientific and a clinical proctor for Medtronic and has received educational grants from Abbott; MC has received speaker honoraria from Biosense Webster and Abbott. AS is the consultant for Biosense Webster, Boston Scientific, and Abbott. AS is a clinical proctor for Medtronic and Boston Scientific and has received educational grants from Abbott; AS has received speaker honoraria from Biosense Webster and Abbott. FMC has received consultant honoraria from Medtronic and Abbott. PO is the consultant for Abbott, Boston Scientific, and Medtronic.

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Supplementary Materials

The following information can be found in the Supplementary Materials: Table S1 presents a complete list of questions and open or multiple-choice relative answers to the web-based survey (mean ± SD or percentage). (*Supplementary Materials*)

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