Evaluation of personal protective equipment use in healthcare workers exposed to ionizing radiation in a Portuguese university hospital

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ABSTRACT | Introduction: Increasing use of ionizing radiation in hospitals exposes healthcare workers to health risks, therefore dosimetric surveillance and anti-radiation personal protective equipment are essential. However, low perception of risk has a negative impact on compliance. Objectives: To qualitatively characterize exposure to ionizing radiation and the compliance with anti-radiation personal protective equipment and personal dosimeters by workers, at a university hospital in Portugal. To investigate the impact of attending health examinations or participating in training activities on this compliance. Methods: Cross-sectional study design administering a questionnaire constructed by the authors to all healthcare workers exposed to ionizing radiation (n = 708). Results: A total of 295 workers completed the questionnaire. They worked in 16 different services using eight different types of ionizing radiation-emitting equipment, the most common of which were fluoroscopes. Lead aprons and thyroid protectors were the anti-radiation personal protective equipment with greatest compliance (61.7 and 55.6%, respectively), while fewer respondents used protective glasses (8.1%) and lead gloves (0.7%). Regular use of a dosimeter was reported by 78.3% of workers and use was associated with participation in training and with attending health examinations. The most frequent reasons given for not wearing anti-radiation personal protective equipment were unavailability (glasses and gloves), presence of a protective barrier, and discomfort. The most common reason for not using a dosimeter was forgetting to do so. Conclusions: Workers who attended training and those who attended health examinations were more compliant with use of dosimeters, indicating that these are useful strategies for improving workers’ compliance with radiation protection measures. Keywords | ionizing radiation; dosimetry; radiation protection; health workers; occupational health.

RESUMO | Introdução: O uso crescente da radiação ionizante em hospitais expõe os profissionais a riscos à saúde, tornando a vigilância dosimétrica e os equipamentos de proteção individual radiológica essenciais. Apesar disso, a baixa percepção de risco influencia negativamente a adesão. Objetivos: Caracterizar qualitativamente a exposição à radiação ionizante e a adesão ao uso dos equipamentos de proteção individual radiológica e do dosímetro individual dos profissionais de um centro hospitalar universitário português. Avaliar o impacto dos exames de saúde ou da participação em ações de formação nessa adesão. Métodos: Estudo transversal com aplicação de um questionário elaborado pelos autores a todos os profissionais expostos a radiação ionizante (n = 708). Resultados: Os 295 trabalhadores que responderam ao questionário trabalhavam em 16 serviços, com oito tipos distintos de equipamentos emissores de radiação ionizante, sendo o fluoroscópio o mais frequente. O avental de chumbo e o protetor de tireoide foram os equipamentos de proteção individual radiológica com maior adesão (61,7 e 55,6%, respectivamente), enquanto os menos usados foram os óculos (8,1%) e as luvas plumbíferas (0,7%). O uso regular do dosímetro foi referido por 78,3% dos trabalhadores, estando associado à participação na formação e à realização de exames de saúde. O uso de equipamentos de proteção individual radiológica foram indispensabilidade (óculos e luvas), presença de barreira de proteção e desconforto. Conclusões: Os profissionais que efetuaram formação e os que efetuaram exames de saúde aderiram mais ao uso do dosímetro, revelando serem estratégias úteis para melhorar a adesão dos profissionais às medidas de proteção radiológica. Palavras-chave | radiação ionizante; dosimetria; proteção radiológica; profissionais de saúde; medicina do trabalho.

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INTRODUCTION

The study of ionizing radiation (IR) and its properties of interaction with materials revolutionized medicine, leading to development of new methods for diagnosis and treatment. However, as application of IR increased, its harmful effects on human health became evident.\textsuperscript{1,2} In addition to causing direct tissue damage, the ionizing potential can also change cellular genetic heritage, increasing the risk of cancer in those exposed and of hereditary changes for their descendents.\textsuperscript{3} Society therefore recognized the need to regulate use of IR in order to protect workers and the public from its negative effects.

The 2013/59/EURATOM Directive\textsuperscript{4} and Decree-Law No. 108/2018,\textsuperscript{5} in Europe and Portugal respectively, set out the principles of radiation protection, making employers responsible for radiation control and occupational health services responsible for surveillance of the health of exposed workers. In addition to health surveillance, occupational health services (OHS) make other essential contributions to worker radiation protection, such as monitoring occupational exposure doses, ensuring correct use of personal dosimeters and protective equipment, and providing training for workers exposed professionally.\textsuperscript{6}

Even though the majority of health workers have a high level of technical-scientific differentiation, they can have a distorted perception of the risks associated with occupational exposure to IR, minimizing the importance of regular use of dosimeters and protective equipment.\textsuperscript{7,8} Two of the several actions that comprise a radiation protection program – professionally-exposed worker health examinations and training in radiation protection – constitute strategies that OHS use to explain the risks and raise awareness about adoption of radiation protection measures.\textsuperscript{6} However, these actions are not always performed and their efficacy for improving compliance to dosimeter use also needs to be evaluated.

The objectives of this study are, therefore, to qualitatively characterize exposure to IR at a university hospital in Portugal, to characterize compliance with use of anti-radiation personal protective equipment (arPPE) and with personal dosimeters by workers professionally exposed to IR, to investigate whether conducting health examinations or participating in training activities are associated with this compliance, and to identify reasons for non-compliance.

METHODS

STUDY DESIGN

This was a cross-sectional study including a descriptive analysis of the data and an analytical component.

STUDY POPULATION AND SAMPLE

The study population comprised all workers at a university hospital in Portugal who were active during the last three months of 2019, were classified as professionally exposed to IR (>1 mSv/year) and, therefore, had a personal dosimeter assigned to them. In turn, the sample comprised all members of the study population who were working at the university hospital during the period and agreed to take part in the study.

INSTRUMENTS

An anonymous questionnaire constructed by the authors was administered to the study sample during the last three months of 2019. The questionnaire covered the following items: an initial section on sociodemographic data (sex, age, hospital service, professional category, and place of exposure to IR); a section on characteristics of exposure to IR (type and frequency of use of IR-emitting equipment); a section on use of arPPE and dosimeters with Likert response scales; and a section on reasons for non-compliance, which included an open response option in addition to several predefined options. The questionnaire also included a question about participation in radiation protection training sessions and another about attendance at the most recent periodic health examination to which they had been invited by the OHS (annual for category A workers and workers over the age of 50 years and every two years for all others).

PROCEDURES

The questionnaire and an informed consent form were distributed on paper to the study population
via the liaison officers at hospital services that have professionally exposed workers. Before distribution of the questionnaire, the university hospital’s OHS held meetings with the service liaison officers in order to make them aware of the importance of their services’ workers completing the questionnaire. Follow-up telephone calls were made to the liaison officers before the date set for returning the questionnaires.

STATISTICAL ANALYSIS OF DATA
Data were collected on paper. Statistical treatment of data was performed using SPSS®, version V27 for Windows. The chi-square test was used for bivariate statistical analysis of dichotomous nominal variables and a 5% significance level was adopted.

ETHICAL CONSIDERATIONS
Completion of the questionnaire was voluntary and anonymous and informed consent was obtained. This study was approved by the Ethics Commission of the university hospital being studied.

RESULTS
DEMOGRAPHIC AND PROFESSIONAL CHARACTERISTICS OF THE SAMPLE OF THE STUDY POPULATION
A total of 708 of the 6,500 workers at the hospital were classified as professionally exposed, constituting the study population. In turn, the study sample comprised 295 workers (41.7% of the study population) with a mean age of 42.7 ± 10.3 years.

The study population was distributed heterogeneously across 16 different services, with the greatest proportions of workers from imaging (202; 28.5%), the operating theater (OT) (127; 17.9%), cardiology (85; 12%), and radiotherapy (64; 9%). There was a slightly greater proportion of physicians than nurses. The three services best represented in the sample, as a proportion of the total study population, were respiratory medicine, pediatrics, and immunohematology (IHT). In turn, the professional category that most responded to the questionnaire was nurses (Table 1).

QUALITATIVE CHARACTERIZATION OF EXPOSURE TO IONIZING RADIATION IN THE STUDY SAMPLE
Qualitative characterization of workers’ exposure was achieved by identifying their use of eight types of equipment grouped into three categories: < once per week, 1 to 4 times per week, and > 5 times per week (Table 2).

The system most used by participants was fluoroscopy (131; 44.4%), followed by teleradiography (RX) (99; 33.6%), and computed tomography (CT) (56; 19%). The systems least used were brachytherapy (5; 1.7%) and radioimmunoassay techniques (1; 0.3%). In terms of the frequency of use, the majority of these systems were used 1 to 4 days per week (n = 209). The linear accelerator (LA) was used more than 5 days per week by 82.5% of the workers who used it.

CHARACTERIZATION OF COMPLIANCE WITH USE OF ARPPE, TRAINING, HEALTH EXAMINATIONS, AND DOSIMETER USE
Workers’ compliance with arPPE and the dosimeter was assessed using Likert scales for frequency of use as “always”, “frequently”, “sometimes”, “rarely”, or “never”, and workers who responded “always” or “frequently” were defined as compliant. The lead protection apron and thyroid protector were the arPPE with best compliance (61.7 and 55.6%, respectively), while the least used arPPE were lead glasses (8.1%) and lead gloves (0.7%) (Table 3).

It was also found that 79.3% of the workers had attended their occupational health examination, 78.3% were compliant with regular use of the dosimeter, and 46.3% stated they had participated in radiation protection training provided by the OHS (Table 4).

Compliance with training, with the health examination, and with regular use of the dosimeter was proportionally lower among workers who were physicians. Female workers had better dosimeter compliance and the difference in relation to male workers was statistically significant (p < 0.05).

Only four of the services with more than 10 participants (IHT, gastroenterology, imaging, and radiotherapy) had greater than 50% compliance with training, while respiratory medicine had the lowest
### Table 1. Characteristics of the population, sample, and representativeness

| Variables                     | Population n (%) | Sample n (%) | Representativeness (%) |
|-------------------------------|------------------|--------------|------------------------|
| **Sex**                       |                  |              |                        |
| Male                          | 247 (34.9)       | 85 (28.8)    | 34.4                   |
| Female                        | 461 (65.1)       | 210 (71.2)   | 45.6                   |
| **Professional category**     |                  |              |                        |
| Physicists                    | 6 (0.8)          | 5 (1.7)      | 83.3                   |
| Nurses                        | 203 (28.7)       | 97 (32.9)    | 47.8                   |
| Therapeutic diagnosis technicians | 170 (24.0)     | 77 (26.1)    | 45.3                   |
| Nursing auxiliaries           | 90 (12.7)        | 36 (12.2)    | 40                     |
| Physicians                    | 239 (33.8)       | 80 (27.1)    | 33.5                   |
| **Service**                   |                  |              |                        |
| Respiratory medicine          | 11 (1.6)         | 11 (3.7)     | 100                    |
| Pediatrics                    | 24 (3.4)         | 23 (7.8)     | 95.8                   |
| Immunohematology              | 21 (3.0)         | 18 (6.1)     | 85.7                   |
| Urology                       | 38 (5.4)         | 26 (8.8)     | 68.4                   |
| Radiotherapy                  | 64 (9.0)         | 43 (14.6)    | 67.2                   |
| Heart and chest surgery       | 3 (0.4)          | 2 (0.7)      | 66.7                   |
| Gastroenterology              | 28 (4.0)         | 17 (5.8)     | 60.7                   |
| Stomatology                   | 31 (4.4)         | 16 (5.4)     | 51.6                   |
| Clinical pathology            | 2 (0.3)          | 1 (0.3)      | 50                     |
| Cardiology                    | 85 (12.0)        | 39 (13.2)    | 45.9                   |
| Orthopedics                   | 23 (3.2)         | 10 (3.4)     | 43.5                   |
| Operating theater             | 127 (17.9)       | 44 (14.9)    | 34.6                   |
| Imaging                       | 202 (28.5)       | 40 (13.6)    | 19.8                   |
| Neurosurgery                  | 28 (4.0)         | 4 (1.4)      | 14.3                   |
| Vascular surgery              | 17 (2.4)         | 1 (0.3)      | 5.9                    |
| Nephrology                    | 4 (0.6)          | 0 (0)        | 0.0                    |
| **Total**                     | 708 (100.0)      | 295 (100.0)  | 41.7                   |

### Table 2. Qualitative characterization of systems that emit ionizing radiation (IR)

| Systems                        | Frequency (days/week) | Total (n) |
|--------------------------------|-----------------------|-----------|
|                                | < 1 | 1 to 4 | > 5 |                  |
| Teleradiography                | 10  | 61     | 28  | 28.3 | 99 |
| Computed tomography            | 7   | 32     | 17  | 30.4 | 56 |
| Fluoroscopy                    | 14  | 84     | 33  | 25.2 | 131|
| Angiography                    | 3   | 15     | 10  | 35.7 | 28 |
| Linear accelerator             | 2   | 5      | 33  | 82.5 | 40 |
| Brachytherapy                  | 0   | 3      | 2   | 40.0 | 5  |
| Blood product irradiator       | 3   | 8      | 7   | 36.8 | 18 |
| Radioimmunoassay               | 0   | 1      | 0   | 0.0  | 1  |
| **Total**                      | 39  | 209    | 130 | 378  |    |

Some workers habitually used more than one type of system.
compliance with training. Compliance with health examinations was better than compliance with training, but nevertheless was below 80% for the pediatrics and urology services. These two services and also the respiratory medicine service had the lowest proportions of workers compliant with dosimeter use (Table 4).

Training in radiation protection and attendance at the health examination were both positively associated with regular use of the dosimeter, with statistical significance (Table 5).

**Table 3.** Characterization of compliance with use of anti-radiation personal protective equipment (arpPE)

| Equipment           | Compliance | Non-compliance |
|---------------------|------------|----------------|
| Lead aprons         | 182 (61.7%)| 113 (38.3%)    |
| Thyroid protector   | 164 (55.6%)| 131 (44.4%)    |
| Lead glasses        | 24 (81%)   | 271 (919)      |
| Lead gloves         | 2 (07%)    | 293 (993)      |

**Table 4.** Participation in training and health examination and dosimeter use among the workers studied: by sex, professional category, and service

| Variables                      | Training n (%) | Health examination n (%) | Dosimeter n (%) |
|--------------------------------|----------------|--------------------------|-----------------|
|                                 | Yes | No | Yes | No | Yes | No | |
| Sex                            |     |    |     |    |     |    |    |
| Female                         | 103 (51.3%) | 98 (48.7%) | 166 (82.2%) | 36 (17.8%) | 174 (82.9%) | 36 (17.1%) |    |
| Male                           | 29 (34.5%)  | 55 (65.5%)  | 60 (72.3%)  | 23 (27.7%)  | 58 (68.2%)  | 27 (31.8%)  |    |
| Professional category          |     |    |     |    |     |    |    |
| Nursing auxiliaries            | 13 (38.2%)  | 21 (61.8%)  | 29 (85.3%)  | 5 (14.7%)   | 28 (77.8%)  | 8 (22.2%)   |    |
| Nurse                          | 35 (36.5%)  | 61 (63.5%)  | 82 (85.4%)  | 14 (14.6%)  | 78 (80.4%)  | 19 (19.6%)  |    |
| Physicists                     | 3 (75.0%)   | 1 (25.0%)   | 4 (100.0%)  | 0 (0.0)     | 4 (80.0%)   | 1 (20.0%)   |    |
| Physicians                     | 23 (29.9%)  | 54 (70.1%)  | 53 (69.7%)  | 23 (30.3%)  | 46 (57.5%)  | 34 (42.5%)  |    |
| Therapeutic diagnosis technicians | 58 (78.4%)  | 16 (21.6%)  | 58 (77.3%)  | 17 (22.7%)  | 76 (98.7%)  | 1 (1.3%)    |    |
| Service                        |     |    |     |    |     |    |    |
| Operating theater              | 20 (45.5%)  | 24 (54.5%)  | 38 (86.4%)  | 6 (13.7%)   | 37 (84.1%)  | 7 (15.9%)   |    |
| Cardiology                     | 14 (37.8%)  | 23 (62.2%)  | 32 (86.5%)  | 5 (13.5%)   | 36 (92.3%)  | 3 (7.7%)    |    |
| Heart and chest surgery        | 0 (0.0%)    | 2 (100.0%)  | 1 (500.0%)  | 1 (500.0%)  | 2 (1000%)   | 0 (0.0)     |    |
| Vascular surgery               | 0 (0.0%)    | 1 (100.0%)  | 1 (100.0%)  | 0 (0.0)     | 0 (0.0)     | 1 (100.0%)  |    |
| Stomatoloy                     | 6 (37.5%)   | 10 (62.5%)  | 14 (87.5%)  | 2 (12.5%)   | 11 (68.8%)  | 5 (31.2%)   |    |
| Gastroenterology               | 9 (600%)    | 6 (400%)    | 12 (800%)   | 3 (200%)    | 12 (706%)   | 5 (294%)    |    |
| Imaging                        | 23 (62.2%)  | 14 (37.8%)  | 33 (86.8%)  | 5 (13.2%)   | 39 (975%)   | 1 (2.5%)    |    |
| Immunohematology               | 14 (82.4%)  | 3 (17.6%)   | 15 (88.2%)  | 2 (11.8%)   | 18 (1000%)  | 0 (0.0)     |    |
| Neurosurgery                   | 1 (25.0%)   | 3 (75.0%)   | 3 (75.0%)   | 1 (250.0%)  | 0 (0.0)     | 4 (1000%)   |    |
| Orthopedics                    | 2 (200%)    | 8 (800%)    | 6 (600%)    | 4 (400%)    | 11 (100%)   | 9 (900%)    |    |
| Clinical pathology             | 1 (1000%)   | 0 (0.0)     | 1 (1000%)   | 0 (0.0)     | 1 (1000%)   | 0 (0.0)     |    |
| Pediatrics                     | 7 (30.4%)   | 16 (69.6%)  | 16 (69.6%)  | 7 (30.4%)   | 14 (609%)   | 7 (391%)    |    |
| Respiratory medicine           | 1 (91%)     | 10 (909%)   | 9 (81.8%)   | 2 (18.2%)   | 5 (454%)    | 6 (546%)    |    |
| Radiotherapy                   | 27 (64.3%)  | 15 (35.7%)  | 30 (71.4%)  | 12 (28.6%)  | 42 (977%)   | 1 (2.3%)    |    |
| Urology                        | 7 (280%)    | 18 (720%)   | 16 (667%)   | 8 (333)     | 14 (538)    | 12 (462)    |    |
| Total                          | 132 (46.3%) | 153 (53.7%) | 226 (79.3%) | 59 (20.7%)  | 232 (78.6%) | 63 (21.4%)  |    |
was forgetfulness. In turn, the principal reasons for not wearing arPPE were i) unavailability of the equipment at the service (lead gloves and glasses); ii) use of a protective radiation barrier, presuming the arPPE to thus be redundant; and iii) the discomfort of wearing them. It was also stated that wearing the equipment interfered with the quality of the technique being executed, in the case of lead gloves (Table 6).

**DISCUSSION**

The sample analyzed accounted for 41.7% of the study population. However, since this was a heterogeneous population that included several groups of workers from different services, it is important to consider the representativeness of each subset, in order to enable extrapolation of the results to our population. The sex distribution was roughly proportional to that of the study population, with a predominance of females. The best represented professional category was the physicists (83.3% agreement), which is probably because this is a small group (n = 6), facilitating contact for administration of the questionnaire. The next best represented were nurses (47.8% agreement), therapeutic diagnosis technicians (TDT, 45.3%) and nursing auxiliaries (40%). Paradoxically, the worst represented group in the sample was physicians (33.3%), who are the largest group in the population. According to some authors, this may be because physicians underestimate their own exposure to IR. The authors believe that more time should be invested in contact with this professional category, in order to identify their motivations and adapt future interventions to them.

There are 16 services at the hospital that conduct activities involving use of IR, 11 of which had at least 40% representativeness in our sample. The respiratory medicine, pediatrics, and IHT services had the highest representativeness, reaching at least 85% of the population, which confers reliability on the conclusions extracted from the study. In contrast, the imaging and OT services were among the five least represented, despite being the most frequent in the population, significantly limiting extrapolation of the results. Therefore, it could be important to conduct interventions targeting these services in the future. It would be interesting to investigate which characteristics, specifically within the ambit of the culture of safety within these services, may have motivated their members to participate in the study or not.

**Table 5.** Association between compliance with use of the dosimeter and participation in training, attendance at the health examination, and sex of workers

| Dosimeter | Yes | No | p-value * |
|-----------|-----|----|-----------|
| Training  |     |    |           |
| Yes       | 119 (90.2) | 13 (9.8) | < 0.05 |
| No        | 106 (69.3) | 47 (30.7) |           |
| Health examination |  |    |           |
| Yes       | 187 (82.7) | 39 (17.3) | < 0.05 |
| No        | 38 (64.4) | 21 (35.6) |           |
| Sex       |     |    |           |
| Female    | 174 (82.9) | 36 (17.1) | < 0.05 |
| Male      | 58 (68.2) | 27 (31.8) |           |

* Chi-square test.

**Table 6.** Reasons for non-compliance with arPPE and dosimeter

| Reasons for compliance | arPPE | Dosimeter |
|------------------------|-------|-----------|
|                        | Useless | Unavailable | Unaware | Protected by a barrier | Forgetfulness | Discomfort | Unreliable | Total |
| arPPE                  | 13 (41) | 141 (43.9) | 3 (0.9) | 97 (30.2) | 4 (1.2) | 67 (20.9) | N/A     | 321   |
| Dosimeter              | 11 (16.5) | 5 (7.5) | 0 | N/A | 46 (68.7) | N/A | 5 (7.5) | 67    |

arPPE = anti-radiation personal protective equipment; N/A = not applicable.
QUALITATIVE CHARACTERIZATION OF EXPOSURE TO IR

The system used with greatest frequency was the LA, since 82.5% (n = 33) of the workers who used it stated they did so on more than 5 days per week. However, LA has a very effective system for collective protection and risk is primarily related to a serious accidental failure of the protection system, and workers who operate it have been trained specifically to do so (they are radiotherapy technicians). Indeed, other systems that are used with lower weekly frequency (categorized as “1 to 4 days per week”) and emit significantly lower IR doses, as is the case of the fluoroscope, are cause for greater concern. This is because the professionals using it may be exposed to a considerable dose of IR because of their proximity to the source and because protection is dependent on correct and consistent use of arPPE. It is thus essential that these workers use the dosimeter regularly, so that their exposure dosage can be quantified, and that they use the appropriate arPPE for each type of procedure/system. Despite the diversity of systems and services involved, this university hospital does not have a nuclear medicine department, since use of radioisotopes is limited to brachytherapy and radioimmunoassays (Clinical Pathology Service). Marking and study of sentinel lymph nodes with technetium-99m can expose health workers to IR. However, according to a prior study, the estimated dose in pathology department workers was well below 1 mSv per annum.

CHARACTERIZATION OF COMPLIANCE WITH arPPE, TRAINING, HEALTH EXAMINATION, AND DOSIMETER USE AND THE REASONS FOR NON-COMPLIANCE

Although the dosimeter is a light device that is easy to use, 21.4% of the sample stated they did not use it regularly. The main reasons given were forgetfulness (68.7%) and perceived uselessness (16.5%) or unreliability (7.5%). Five workers who had started work recently were waiting for their first dosimeter and endorsed dosimeter unavailability as the reason for non-compliance. It is possible that, as working conditions have improved, specifically with regard to radiation protection, and a reduction in observable effects on health has been documented over recent years, workers are less interested in compliance with dosimeter use. It is therefore important to invest in training these workers on the importance of individual dosimetric monitoring. Regardless, compliance was much higher than has been observed in other studies, in which it was found that around 70% of urologist physicians (specialists and residents) did not regularly use a dosimeter.

With regard to arPPE, the majority of the workers stated that they regularly wore lead aprons (61.7%) and thyroid protectors (55.6%). Compliance with wearing lead glasses and gloves was significantly lower (8.1% and 0.7%, respectively). Apparently, compliance with all types of arPPE was low, varying according to the type of protective equipment. However, the format of the questionnaire constitutes a limitation of the study, since it should ideally have been adapted to each workplace/service and radiological technique. The main reasons given for non-compliance with arPPE were unavailability (lead gloves and glasses [43.9%]), use of a protective barrier during emission of IR (30.2%), and discomfort (20.9%). It should be noted that these proportions do not necessarily indicate failure to comply with safety procedures, since not all activities require operators to wear arPPE. Examples of such activities performed at this hospital are the LA, the blood product irradiator, and, to a certain extent, CT and conventional X-rays, for which it is unnecessary for the worker to be present in the room during IR emission and collective protection barriers are sufficient. Targeted studies should therefore be designed to characterize the need for intervention with greater precision.

It should be highlighted that the very low compliance with wearing lead gloves and glasses was attributed to unavailability (or insufficient availability) of these arPPE at the services or to workers being unaware of their existence. In addition to their use only being applicable to certain specific contexts (wearing glasses during angiography), there is greater resistance to wearing them because of both discomfort and their influence on technical performance, discouraging compliance further still.
Training in radiation protection, which is voluntary, has been made available free of charge by the hospital's OHS, since 2006. Where there is interest, training can also be provided at the services themselves. Despite these efforts made by the OHS, only 46.3% of the participants stated they had at least once taken part in training on radiation protection. This could be because of the continuous turnover of the population to be trained, by the institution's level of safety culture, and by the low perception of risk of certain groups of workers.

It is interesting to note that the diagnostic and therapeutic technicians and also the physicists, who have already had training in radiation protection as part of their professional education, were the groups who most complied with the training provided by the OHS, possibly because they have a greater awareness of the subject, giving them a greater perception of the risks. In contrast, the physicians were the group with least adherence with training, despite being the workers that most performed fluoroscopy/angiography procedures, during which they are positioned very close to the IR source and, therefore, are susceptible to receiving greater doses of IR. Their elevated technical differentiation could possibly constitute an obstacle to perception of risk of a professional nature, since IR is seen as merely an “instrument for visualization” for performing a wide range of different procedures. The differences observed between services appears to be compatible with the same reasoning, since the less compliant services were those in which the techniques are primarily performed by physicians and nurses. Similar logic to that applied to training may also explain the differences observed in compliance with use of the dosimeter. It should nevertheless be noted that the management of the gastroenterology department manifested interest in radiation protection, showing the importance of involving the heads of departments in development of a safety culture.

Compliance with health examinations is possibly dependent on perception of the risk related to exposure to IR, but also on other factors, such as accessibility of medical consultations, existence of health problems with implications for professional activity, and perception of risk of other types (mechanical, biological, and psychosocial), thereby explaining the high degree of compliance among nursing auxiliaries and nurses. It was also noted that females had higher compliance with training (51.3%), health examinations (82.2%), and dosimeter use (82.9%). One possible reason is a greater sensitivity to reproductive health and general knowledge about the teratogenic effects of IR.

Training and attendance at health examinations were associated with greater compliance with regular use of the dosimeter. Therefore, these strategies employed by the OHS merit intensification and optimization, in conjunction with other strategies for radiation protection (such as preventative maintenance of equipment and optimization of reference dosages, among others).

**CONCLUSIONS**

Use of IR in hospital settings is highly diversified. In our study, eight types of systems were distributed across 16 services that used them regularly, potentially exposing workers to very different IR dosages. The fluoroscope was used by the largest number of exposed workers.

Regular compliance with use of the dosimeter was only 78.6%, and forgetfulness was the main reason for non-compliance. Workers who had attended training and health examinations were more compliant with dosimeter use.

Lead aprons and thyroid protectors had the highest compliance (61.7 and 55.6%, respectively) and non-utilization was primarily related to use of protective barriers (making them unnecessary in these cases) and also with discomfort. In addition to discomfort, the main reasons for the very low compliance with wearing lead glasses (8.1%) and gloves (0.7%) were irregular availability at the services and interference with execution of technical procedures.

**Authors’ contributions**

JAAR, DF and EMSL were responsible for the study concept. JAAR was also responsible for formal analysis of data and writing – original draft of the text. DF, AL, LMG, and EMSL participated in the investigation, in sourcing resources, and in writing – revision and editing of the text. All authors approved the final version submitted and take public responsibility for all aspects of the study.
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