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Original Article

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Experimental Assessment of Workplace Radiation Exposure in Diagnostic X-ray Medical Imaging Centres in Benin from 2019 to 2020

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Abstract

The ease of prescribing radiological examinations has prompted an expansion in radiological procedures and, consequently, an increase of occupational dose to medical imaging workers. However, little is known about radiation exposure in the workplace of medical radiology professionals in many countries, and in Benin particularly. The purpose of this study was to assess ambient radiation doses in diagnostic X-ray medical facilities in Benin and to observe whether exposure levels are below reference levels. A total of 72 public and private medical imaging centres participated in a cross-sectional study carried out from June 2019 to February 2020 in Benin. These centres had 59 X-ray, four chest and six computed tomography (CT) scan rooms. A calibrated radiameter able to measure short, pulsed or continuous X fields and gamma/beta (50 nSv to 10 Sv) was used to measure exposure levels in these functional rooms. Scattered X-ray doses and exposure time from radiological examinations both behind the lead glass of the control area to assess the levels of exposure of professionals and outside of the examination room to evaluate the level of exposure of the public (including non-exposed workers) have been provided. Equivalent doses estimated per hour were compared with the reference levels of 7.50 and 0.05 µSv per hour for workers and the public, respectively. At the control area, the mean/median (min-max) equivalent doses were 0.09/0.07 (0.00–0.21), 2.39/0.13 (0.00–75.67), and 228.39/28.65 (0.39–869.75) µSv per hour for the chest, X-ray, and CT-scan rooms, respectively. Among 69 examination rooms, 13.04% of the equivalent dose estimated in the workplace behind the lead glass was greater than 7.50 µSv per hour; 65 out of 69 examination rooms

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What's Important About This Paper?

In Benin, the number of examinations and use of medical imaging devices has been increasing over the past decade, but the first law on radiation and nuclear safety was adopted in 2018 and the Regulatory Authority Body became operational in 2020. Given this context, this study assessed radiation exposures in work areas and public areas of medical imaging centers in Benin. Equivalent doses were in excess of reference levels at the control panel (behind lead glass) in 13% of medical imaging rooms. Radiation exposure controls must be upgraded and dosimetry program should be implemented to monitor exposures of employees.

showed that 40.00% of the equivalent dose estimated behind the doors was greater than 0.05 µSv per hour. These results demonstrated that current controls, including leaded glass separating the control panel and leaded doors between the examination room and the corridor, are inadequate to limit radiation exposures. The controls must be upgraded and a dosimetry program should be implemented to monitor exposures of employees, patients, and visitors.

Keywords: Benin; medical imaging; occupational exposure; X-ray; workplace ambient dosimetry

Introduction

Ionizing radiation is used widely for diagnostic imaging, and commonly used in the clinical diagnosis and treatment of cancer; however, its improper use can induce health consequences. The radiation exposure of patients, workers, populations, and environment from medical, industrial, and teaching/research applications has to be assessed and, if necessary, controlled (International Atomic Energy Agency, 2018). There is a noticeable increase year after year in the frequency of radiological procedures (Samer *et al.*, 2016). Therefore, during the last decade, the number of exposed health workers in departments of nuclear medicine and diagnostic radiology has increased (Linet *et al.*, 2010; Covens *et al.*, 2012; Pauwels and Bourguignon, 2012; Smith-Bindman *et al.*, 2012; Al-Abdulsalam and Brindhaban, 2014). In 2008, the estimated worldwide annual number of diagnostic and interventional radiological procedures (including dental) was 3.6 billion (International Commission on Radiological Protection, 2011; Eze *et al.*, 2013). In Africa, medical exposure to ionizing radiation has increased with the wide availability of computed tomography (CT) scan and conventional radiology devices with the consequences of the increased risk of radio-induced cancer (Neossi Guena *et al.*, 2018). The same observation was made by Suliman *et al.* in their study in the Sudan (Suliman *et al.*, 2015) and Eze *et al.* in Nigeria (Eze *et al.*, 2011). Therefore, it is necessary to ensure a healthy workplace for medical workers.

In Benin, medical imaging can be mainly summed up in standard radiology, CT-scan, mammography, and dental X-ray. Between 2015 and 2019, the number of radiological devices has increased from 25 to 36 in public centres (Dpmed-Ministry of Health, 2019), with a consequent increase in radiological procedures. Unfortunately, the development of this radiological equipment took place in an unregulated environment. During X-ray examinations, radiographers stand behind a radiation shielding lead glass (one part of the screen) in control area, which is supposed to guarantee the reference level of 7.50 µSv per hour is not exceeded in the workplace (supervised area) (International Atomic Energy Agency and European Commission, 2014). It is because of the risk of thyroid and female breast cancers, as well as cataracts (Wang *et al.*, 2002, 2015; Memon *et al.*, 2010; Sun *et al.*, 2016), that we focused our study on exposure in the workplace (control area) from which radiographers observe patients. Since the examination room doors, which are generally not far from the waiting rooms in Benin, are used by both health workers and public members, it is also important to assess the doses to which those latter are exposed to behind the doors in the corridor. The reference level required for members of the public 0.05 µSv per hour (International Atomic Energy Agency and European Commission, 2014). In March 2018, Benin adopted a law on radiation safety and nuclear safety (Benin's Government, 2018) and the Regulatory Authority Body has been functional since 20 August 2020 (Benin's Government, 2020). Furthermore, Benin also has a new centre for occupational dose monitoring, which is performing technical controls before starting its activities.

The purpose of this study is to assess ambient radiation doses in X-ray medical imaging centres and to observe whether the exposure levels are below required reference levels. (International Atomic Energy Agency and European Commission, 2014).

Methods

Data collection and processing

A cross-sectional study was carried out from June 2019 to February 2020 in medical imaging centres in Benin. These public and private centres voluntarily agreed to participate in this study. Preliminary information regarding the type and the location of different hospitals were obtained from the Ministry of Health of Benin. Some centres were excluded for technical problems and misunderstandings: some hospital managers thought that the study was about a control of the ministerial authorities (n = 2); others had built the radiology rooms but had not yet equipped them (n = 2), and finally some centres had machines under repair (n = 4). At the time of measurement, some examination rooms were excluded for equipment that was broken or under repair. Only functional X-ray devices were selected in this study of X-ray, chest, and CT-scan rooms. The results of the identification and selection process are displayed in a flow chart in Fig. 1.

Before measuring the radiation dose in these different examination rooms, a self-completion questionnaire (in Supplementary Material) designed in-line with the objectives of the study was used, to obtain different information from service managers about the characteristics of examination rooms, such as (i) dimensions of the examination rooms in centimetres (cm), (ii) X-ray device specifications, and (iii) number of examinations per year.

Ethical consideration

This research was not human subjects research, but to the agreement of the hospital managers was requested and obtained before carrying out the radiation dose measurements in the medical imaging centres.

Measurements of workplace doses

Both following instruments were used: (i) a meter to measure the room dimensions and (ii) a AT1123 radiameter able to measure short, pulsed or continuous X-ray fields and gamma/beta (50 nSv to 10 Sv). The radiameter was calibrated on 14 May 2019 (Supplementary Material) and was used to measure exposure levels (Hi*(10)) in these functional rooms. Ambient equivalent dose (Hi*(d)) at a point in a radiation field is defined as the equivalent dose that would be produced by the corresponding field in the ICRU sphere at a depth (d) (in mm) (International Commission on Radiation Units and Measurements, 1985; Chinangwa *et al.*, 2017). All measurements were carried out by the same operator.

At each site, the first measurement was the background equivalent dose level. The patient's body was simulated by a phantom made of plexiglass filled with

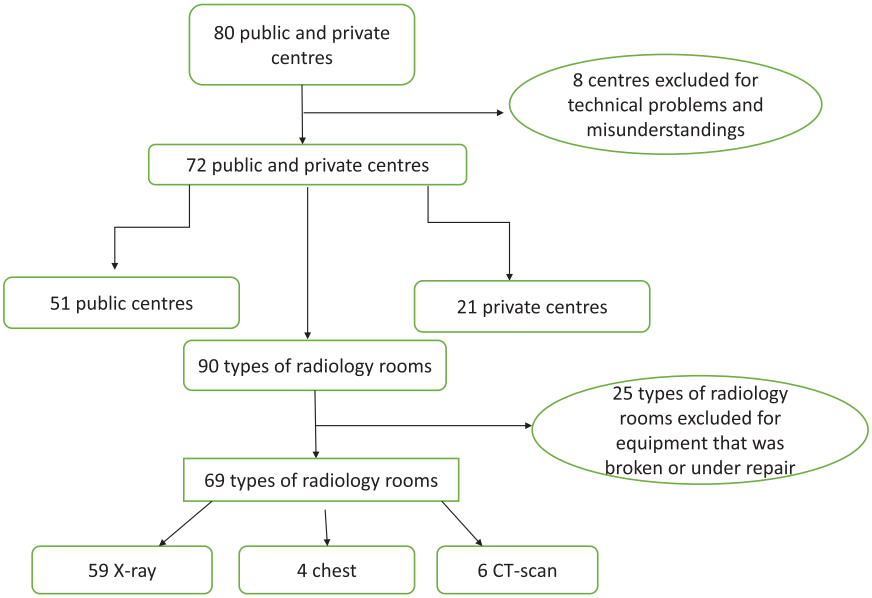

Figure 1. Flow chart selection process of types of radiology room in Benin.

water [polyethylene high density (PEHD), 0.95 g/cm^3], with a volume of 26.48 litres, instead of the regular phantom in polymethacrylate of methyl (PMMA, 1.05 g/cm^3) 'Human Body'. The measurements were made at the workplace of the radiographer, behind the lead glass screen of the control areas, and in the corridor, behind the lead doors of examination rooms (Figs 2 and 3). The measurements were carried out at height corresponding to the usual level of the chest of occupationally exposed workers, as requested by the IAEA (International Atomic Energy Agency and International Labour Office, 2018).

The lumbar examination, chest, and CT abdomen-pelvis were chosen as referents because of their large diffusion volumes (scattered radiation) compared to those in other examinations carried out at the same distance (Institut national de recherche et de securite, 2010), and frequency of achievements. The conditions for carrying out these examinations are described in Supplementary Tables A and B of the Supplementary Material. The image acquisition parameters used were milliampere.seconds (mAs) and kilovoltage (kV), as these are the parameters that radiographers usually use during reference examinations (International Commission on Radiological Protection, 1975; Zaichick, 2013). Image acquisition parameters are summarized in Supplementary Tables A and B (Supplementary Material).

Equivalent dose rates and exposure times were measured for one examination (Supplementary Tables C–E in Supplementary Material) at each site. In order to obtain close-to-reality equivalent dose rates, a correction factor (T) was calculated for the different types of reference examinations, as the ratio between the patient and phantom equivalent dose carried out in the same experimental conditions. The values of correction factor (T) obtained were 0.63 ± 0.24 for chest radiography and 1.26 ± 0.30 for both lumbar radiography and CT-scan abdomen-pelvis. The equivalent dose patients or equivalent dose phantoms used are described in Supplementary Tables G and H in the Supplementary Material.

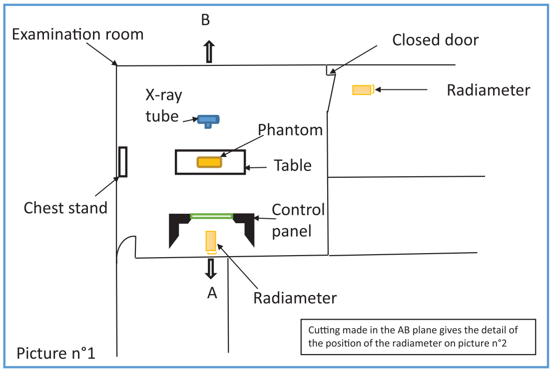

Figure 2. Radiameter position during measurements for control panel and corridor.

Formula used

It is possible, on the basis of the questionnaire, to estimate the mean number of examinations (lumbar and chest radiography, as well as CT-scan abdomen-pelvis) per hour. These different numbers are summarized in Supplementary Tables A and B (Supplementary Material). Equivalent dose rates were integrated in 1 h to obtain an equivalent dose (H_{ih}*(10)), which was estimated by the following formula:

$$(H_{ih} * (10)) = (H_i * (10)) \times t \times n,$$

where (H_i*(10)) in µSv/hr are equivalent dose rates estimated after affecting the correction factor (T) at equivalent dose rates measured; t: time of exposure in hour (h) per examination; n: number of examinations performed in 1 h. This formula was used to compare workplaces and corridors to radiation protection criteria.

Statistical analysis

(H_{ih}*(10)) was compared to the reference levels of 7.50 µSv for the supervised areas (control areas) and 0.05 µSv for public places (see in the Supplemental Materials for explanatory note of reference level calculations) (International Atomic Energy Agency and International Labour Office, 2018). The data collected were analysed for the questionnaire and dosimetric data, using SAS® version 9.4, R-Studio © 2009–2019, version 1.2.5019, and software tool IH STAT. Statistical inference was based on two-sided tests, and a P-value ≤0.05 was considered statistically significant. According to the distribution of the dose, parametric and nonparametric tests were carried out to obtain comparisons and correlations between different values.

Results

Out of 80 public and private centres, 72 participated in this study. In total, there were 73 X-ray, 4 chest, and 13 CT-scan rooms identified in these centres, of which 59 X-ray, 4 chest, and 6 CT-scan rooms were evaluated; all were operational, and the participation rate was 80.82%, 100.00%, and 46.15%, respectively (Table 1). Based on centre registers, we recorded, for the year 2019, 181,140 and 11,472 examinations for standard radiology (including chest radiography) and CT-scan procedures, respectively.

The AT1123 radiameter allowed us to carry out different measurements behind the screen (lead glass and

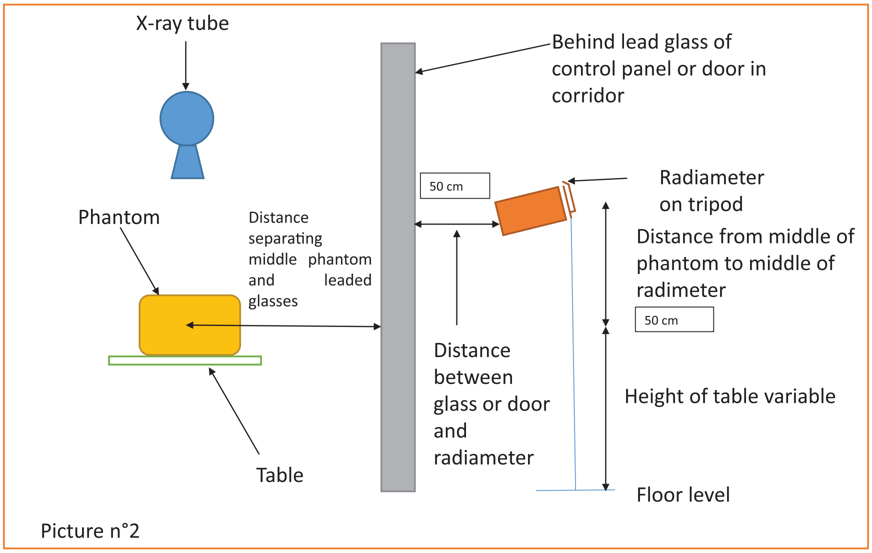

Figure 3. Radiameter position relative to the radiation shielding lead glass or examination room door.

Table 1. Types of centres, radiology equipment, and radiology rooms in Benin.

	General statistic[a]	Participants[b]	(%)[c]
Types of centres	80	72	90.00
Public	53	51	96.22
Private	27	21	77.78
Radiology equipment	115	69	60.00
Yes	90	69	76.67
No[d]	25	0	0
Types of radiology rooms	90	69	76.66
X-ray	73	59	80.82
Chest	04	04	100.00
CT-scan	13	06	46.15

[a] Statistics of centres, rooms, and radiology equipment;
[b] Centres and examination rooms that participated in this study;
[c] Ratio participants/ whole country;
[d] Equipment broken or under repair.

doors). For equivalent dose estimated behind the lead glass in control area, the mean doses were 2.39, 0.09, 228.39 µSv for the X-ray, chest, and CT-scan rooms, respectively. These equivalent dose estimates were increased from the chest rooms to the CT-scan. Similar trends were observed in the corridor (Table 2).

The comparison carried out between equivalent dose estimated per hour at control area and corridor in the X-ray rooms showed that they were statistically significantly different (P-value < 0.0001). In contrast, at both these levels, in the chest and CT-scan rooms, they were not statistically significantly different for the same points considered. For all rooms, there was a strong statistically significant correlation between equivalent doses estimated per hour at control area and corridor ($r = 0.72$, P-value <0.0001).

At the control area, some equivalent doses estimated per hour at control area were higher than the reference levels, 6.78% and 83.33% (Table 2) for X-ray and CT-scan rooms, respectively. Equivalent doses estimated per hour at corridor of X-ray and CT-scan rooms were above the reference levels, 33.90% and 83.33% (Table 2), respectively. For the chest rooms, only half of the equivalent doses estimated per hour at the corridor were above the reference levels. Statistically significant difference was noted between the equivalent dose estimated

Table 2. Statistic summary of equivalent doses (H_{ih}*(10)) in µSv for different examination rooms and comparison with reference levels.

Type of rooms	Measurement location	N	Mean (µSv)	Median (µSv)	[Min-Max] (µSv)	*P*-value (Between mean control area and corridor)	Reference level (µSv)	*P*-value[c] (Between mean control area or corridor and Reference level)	(%)[d]
X-ray rooms	Control Area[e]	59	2.39	0.13	0.00–75.67	< 0.0001[a]	7.50	< 0.0001	6.78
	Corridor[f]	57	0.94	0.02	0.00–24.72		0.05	0.06	33.90
chest rooms	Control Area[e]	4	0.09	0.07	0.00–0.21	0.11[b]	7.50	-	0.00
	Corridor[f]	2	0.04	0.04	0.00–0.08		0.05	-	50.00
CT-scan rooms	Control Area[e]	6	228.39	28.65	0.39–869.75	0.16[b]	7.50	-	83.33
	Corridor[f]	6	90.82	68.04	0.00–245.33		0.05	-	83.33
All rooms	Control Area[e]	69	21.91	0.18	0.00–869.75	< 0.0001[a]	7.50	< 0.0001	13.04
	Corridor[f]	65	9.21	0.02	0.00–245.33		0.05	0.06	40.00

[a] *P*-value obtained from *t*-test comparison between equivalent dose to the control area and corridor with lognormal distribution;

[b] *P*-value of comparison obtained from Wilcoxon's nonparametric test between equivalent dose to the control area and corridor;

[c] *P*-value obtained from *t*-test comparison between mean and reference level with lognormal distribution of mean;

[d] Percent of Equivalent dose estimated > reference level (µSv);

[e] Point situated behind the lead glass of control area;

[f] Point situated behind the lead doors of examination room outside in corridor.

per hour at control area of X-ray rooms and all examination rooms and reference levels.

Overall, for the 69 control areas and 65 corridors, 13.04% and 40.00% (Table 2) of equivalent dose estimated per hour were higher than reference levels, respectively. We noted a negative correlation between the area of examination rooms and equivalent dose estimated per hour at control area, which was statistically insignificant. The same negative correlation was found between the distance separating the phantom's middle to the lead glass and equivalent dose estimated per hour at control area. In contrast, this negative correlation was statistically significant.

Discussion

Since its independence in 1960 and its accession to the IAEA in May 1999, Benin did not have a law on radiological safety and nuclear security until March 2018. The Regulatory Authority Body just started its activities on 20 August 2020. Our study set out to take stock of the situation regarding the installation of standard radiology and CT-scan rooms in Benin.

This study brings us to look at ambient dosimetry, which is a section of the workplace safety assessment. Workplace safety assessment is essential for effective dosimetric monitoring and epidemiological purposes. It includes, apart from ambient dosimetry, individual dosimetry and the study of plausible dysfunctions, which can cause accidental irradiation (Antoni and Bourgois, 2013; Bourgois and Antoni, 2019). The objective of this study was to classify the workplace, in particular the workplace (control areas) of the different standard radiology and CT-scan rooms. The classification of workers will not be discussed in this study.

Due to technical problems and misunderstandings of the study's purpose, eight centres listed in the results could not participate in this study. Among the results, we remarked that the equivalent doses increased from chest rooms to those of CT-scan rooms. This trend in the increasing evolution of the equivalent doses is justified by the fact that the milliampere.seconds loads used increases from the chest to CT-scan rooms.

The equivalent dose mean/median (min-max) per hour observed at the X-ray and CT-scan rooms were 2.39/0.13 (0.00–75.67) and 228.39/28.65 (0.39–869.75) µSv, respectively, for measurements carried out at the control area. These figures were high compared to those published by Achuka *et al.* (Achuka *et al.*, 2019), which were 1.62 and 2.65 µSv, respectively. Our figures in X-ray rooms were high compared to mean equivalent doses published by other authors, including 1.61 µSv/h (Salama *et al.*, 2016), 0.95 µSv/h (Haider *et al.*, 2014), 0.82 µSv/h (Skam *et al.*, 2017), and 0.024 µSv/h (University of Maiduguri *et al.*, 2017). When we consider only the median equivalent dose at the control area, X-ray rooms in this study were lower than 1.62 µSv, which is the mean published by Achuka *et al.* (Achuka *et al.*, 2019). Our values of both mean and median at the control area for X-ray rooms was lower than the 3.10 µSv published by Chinangwa *et al.* (Chinangwa *et al.*, 2017). Our relatively high means are explained by the fact that some lead glass did not attenuate the equivalent dose rates correctly. This can be also explained by the fact that the medical imaging devices are not calibrated, since the acquisition by purchases or by donations, therefore, produce high equivalent dose rates. On the other hand, some of the extreme values recorded could be explained by the fact that some examination rooms had openings around the lead glass or did not have lead glass. These extreme values, especially those recorded in the CT-scan rooms, influenced the means. However, the percentage of non-compliance of the lead glass of the X-ray rooms was relatively low, 6.78% compared to the 15% published by Haider *et al.* in Bangladesh (Haider *et al.*, 2014). But, the national law in Bangladesh requires 1.00 µSv instead of 7.50 µSv at international reference levels and national reference levels from the regulatory acts of Benin. In the study by Haider *et al.*, 30% of doors were not in compliance with

Table 3. Correlations between the equivalent doses in µSv estimated at the control area level and area of examination rooms or distance.

	N	Mean (µSv)	[Min-Max] (µSv)	Correlation/*P*-value[a]
Examination rooms area (cm^2)	69	25.80	6.00–51.53	–0.15/0.22
Equivalent dose (µSv)	69	2.39	0.00–75.67	
Distance from phantom to lead glass (cm)	69	270.15	90–542	–0.28/0.02
Equivalent dose (µSv)	69	2.39	0.00–75.67	

[a] *P*-value of correlation obtained from Spearman's nonparametric test between equivalent dose at the control area and examination rooms area or distance from the middle of the phantom to lead glass.

their reference levels compared to 33.90% in our study for the X-ray rooms. We note that the different authors cited in our study did not specify the number of examinations carried out in each room, which can influence the equivalent dose. In addition, their sample of measurements varied from three to 13 against 69 in our study.

A strong positive correlation between glass and doors, (r = 0.72), which is statistically significant ($P < 0.0001$), proves that the lead glass and doors probably contained material with the close density. The weak negative correlations ($r = -0.15$ and $r = -0.28$, respectively) (Table 3) observed between the equivalent dose per hour and area of the examination rooms, on the one hand, and between the equivalent dose per hour and distance separating the phantom's middle and lead glass, on the other hand, shows that increased distance separating the source (scattered radiation) and the control area is associated with decreased equivalent dose. The equivalent dose per hour is proportional to the inverse square of distance that separates the source (scattered radiation) and point of measurements (Institut national de recherche et de securite, 2010). The hospital managers could install X-ray devices in larger rooms. Examination tables and control area must be placed (as far as possible) away from each other.

This study is the first which is carried out in Benin where hospital managers, head of the medical imaging department and exposed workers are involved in the same study with metrology. We have specified the number of examinations, which can be performed in each room, generating the highest equivalent dose per hour. This number of examinations greatly affects the equivalent dose. In addition, our sample was large relative to other studies. However, this study is limited by the phantom used which is not the one usually used in other countries. This can over- or under-estimate the equivalent dose. As a result, we have used a correction factor (T), in order to obtain close-to-reality equivalent dose.

Selection bias was considered in this study because we cannot certify that the list of medical imaging centres was exhaustive and that some centres withdrew from the study. We were not able to carry out the measurements in all the centres. This risk is small, however, as just 2.5% of centres which refused to participate in study.

Conclusion

In summary, out of 69 control areas (behind lead glass) and 65 corridors (behind lead doors) studied, 60 were classified as supervised areas and 39 as public places. Optimization of the radiation time of patients can reduce the equivalent dose for workers, as can quality control of all imaging machines in Benin. The equivalent dose recorded are sometimes relatively high. These results demonstrated that current controls, including leaded glass separating the control panel and leaded doors between the examination room and the corridor, are inadequate to limit radiation exposures. The controls must be upgraded and a dosimetry program should be implemented to monitor exposures of employees, patients, and visitors. Another study using the dosimeter would be useful to complement this work.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

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Conflict of Interest

The authors declare that there is no conflict of interest.

Data Availability

All data are incorporated into the article and its Supplementary Material.

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