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Protection of Patients and the Environment Through Optimization of Radiological Safety in Kinshasa Hospitals in the DRC: Proposals for Pedagogical and Didactic Remediation in the Learning Process at Higher and University Levels for the Optimization and Sustainability of Radiation Protection

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Abstract

The purpose of this research was to propose pedagogical and didactic strategies for teaching radiation protection at higher education and university levels, with the aim of optimizing radiological safety in the Democratic Republic of Congo (DRC). This was done after evaluating the implementation of protective measures against the harmful effects of X-rays in conventional radiology in Kinshasa hospitals. To achieve this, we conducted a survey in 23 Kinshasa hospitals with a sample of 400 health professionals, including 100 radiologists, to assess the level of implementation of radiation protection principles in order to propose pedagogical and didactic remediation in initial training where necessary. In addition to interviewing the respondents, we collected radio-physical parameters to evaluate the degree of irradiation in pediatric and adult

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radiology services in Kinshasa hospitals. After analyzing the data, the following results were recorded: the surveyed health personnel reported that more than 40% of requested radiology examinations are not justified. Eleven services were found to be highly irradiating in pediatrics (48%) and two radiology services in adults (9%). Finally, all surveyed radiologist health personnel in Kinshasa do not know how to evaluate the degree of irradiation in their services. In light of these results, we proposed pedagogical and didactic remediation in radiation protection teaching during initial training to enable future health professionals to demonstrate competencies for optimizing radiological safety.

Keywords

Optimization, Radiation Protection, Pedagogical and Didactic Remediation, Radiological Safety

1. Introduction

The applications of ionizing radiation in the medical field are among the oldest of all. In 2008, the annual number of diagnostic radiology and interventional radiology procedures (including dental) performed worldwide was estimated at 3.6 billion, the number of nuclear medicine procedures at over 30 million, and the number of radiotherapy procedures at over five million 1. The number of these procedures has continued to increase since then. These medical applications have considerable public health benefits [1].

Currently, the most abundant sources of artificial radiation are X-ray emitting devices used in medicine for medical diagnosis (radiodiagnosis) and for the treatment of certain tumors (radiotherapy). Medical applications of ionizing radiation can only be part of medical practice. The radiation protection and radiological safety system should be an element of the system aimed at ensuring compliance with good medical practices in general. However, ionizing radiation can have harmful effects, and a systematic approach should be adopted to balance the ability to use the benefits of their medical applications and the need to minimize radiological risk to patients, workers, and the public [2]-[4].

Irradiation remains the frequent and worrying cause of serious adverse events that occur worldwide. In Chernobyl, about 1800 thyroid cancers were observed in children living in territories close to the power plant. Each year, between 120,000 and 190,000 serious, preventable adverse events occur during hospitalization, and between 700,000 and 110,000 admissions to health structures are due to a serious adverse event related to irradiation [1] [5]. According to epidemiological studies conducted in France and America in 2009 in children, a dose of 2.4 Sv leads to 8.6 probabilities of death, 13 years of life lost per death related to thyroid cancer [6] [7]. In radiation protection, it is assumed that there may be a linear relationship between exposure and cancer risk, without a threshold value below which the risk would be zero. Based on this linear no-threshold model, the probability of developing cancer is assumed to increase with the radiation dose, including in the case of low-dose medical imaging procedures [6]-[8].

In the Democratic Republic of Congo, radiology equipment is being distributed day by day in general reference hospitals as well as in private structures, which would increase the extent of radioactivity throughout the country. The situation of radiation protection training is worrying in the DRC. Very few studies have been conducted in this field. The results of a recent study reflect a low level of involvement of radiologist versus non-radiologist health personnel in compliance with radiation protection standards. A study on the state of patient radiation protection in pediatric radiology [9] [10] revealed a number of violations. In Kinshasa, several radiology services are scattered throughout the city in public and private health structures. And most of them are run by personnel who have not acquired the required knowledge and skills to enable them to promote the optimization of radiological safety. This is why this study had, among other objectives:

- To evaluate the practices of health personnel regarding the observance of radiation protection principles (justification, optimization, and dose limitation) for the protection of patients and the environment against the effects of X-rays;
- To highlight the gaps or didactic deficits in radiation protection teaching requiring adjustments to meet the needs of health science learners, future health personnel, in order to perpetuate the optimization of radiological protection in DRC hospitals.
- To propose didactic remediation in initial training including: restructuring the content of radiation protection teaching and implementing transmission models likely to promote the acquisition of knowledge and skills required for the optimization of radiation protection in conventional radiology.

2. Materials and Methods

2.1. Type of Study

We conducted a cross-sectional study on "protection of patients and the environment through the optimization of radiological safety in Kinshasa hospitals in the DRC: Proposals for pedagogical and didactic remediation in the learning process at higher and university levels for the optimization and sustainability of radiation protection".

2.2. Study Site

Twenty-three Kinshasa hospitals with radiology services constituted the site of our surveys.

2.3. Target Population

Radiologist and non-radiologist health professionals from Kinshasa health structures with radiology services and concerned by the research constituted our target population.

2.4. Sampling

We conducted a survey in Kinshasa hospitals with a sample of 400 health professionals, including 100 radiologists, to assess the level of implementation of radiation protection principles in order to propose, where necessary, pedagogical and didactic remediation in initial training that can enable learners, future health personnel, to acquire the knowledge and skills required for maximizing and sustaining radiological safety. The sample size was calculated based on the Slovin formula to adjust the size according to the finite population (total number of health professionals in Kinshasa). We also used weighted stratified sampling to determine the number of health professionals to be surveyed by category (Radiologist or non-radiologist).

2.5. Inclusion Criteria

- Be a radiologist or non-radiologist health professional
- Be an effective staff member of Kinshasa hospitals to be surveyed and agree to freely answer our questions

2.6. Parameters Studied

In addition to aspects related to the knowledge and practices of health personnel regarding compliance with radiation protection principles, the radiophysical parameters used in the different services were collected to determine the degree of irradiation of the services with regard to the standards of the International Commission on Radiological Protection (ICRP).

2.7. Statistical Calculations

The entrance doses obtained in each radiology unit of the concerned Kinshasa hospitals were compared to those of the ICRP, which serve as diagnostic reference levels (DRLs). For this purpose, the Wilcoxon test was useful as it involved comparable parameters with paired data to allow us to compare the scores of the surveyed hospitals and those of the International Commission on Radiological Protection. The chi-square test also allowed us to analyze the proportions of health personnel in relation to knowledge and practices on radiation protection optimization.

2.8. Expected Impact

The results obtained will allow proposing pedagogical and didactic remediation in radiation protection teaching at higher and university levels to enable learners, future hospital health personnel, to demonstrate competencies in radiation protection in professional life for the optimization of radiological safety.

2.9. Ethical Considerations

On this issue, the relevant provisions were made so as not to harm the respondents. Thus, we were obliged to:

- Explain the respect for confidentiality
- Provide the expected benefits
- Formulate a signed and dated informed consent

3. Results

3.1. Status of Respondents and Health Structures in Kinshasa

Table 1 informs us that many of the surveyed individuals from health structures in the city of Kinshasa were non-radiologists, accounting for 75%.

Table 1. Distribution of respondents according to professional category.

Respondents	Number	%
Radiologists	100	25
Non-radiologists	300	75
Total	400	100

Table 2 indicates that the vast majority of surveyed health structures in the city of Kinshasa were from the public sector, accounting for 65.2%.

Table 2. Distribution of health structures according to their status.

Health structures	Number	%
State-owned	15	65.2
Privates	6	26.0
Faith-based	2	8.8
Total	23	100

3.2. Knowledge of Radiation Protection Standards and Radiation Effects

Based on Table 3, in Kinshasa health structures, there is a statistically significant difference between radiologist health personnel who have knowledge about radiation effects compared to those of other categories ($P < 0.05$).

Table 3. Distribution of surveyed radiologists versus non-radiologists according to knowledge of radiation effects.

Respondents	Knowledge of health personnel on the effects of X-rays		Total
	Sufficient	Insufficient	
Radiologist	80 (20%)	20 (5%)	100 (25%)
Non-radiologist	150 (37.5%)	150 (37.5%)	300 (75%)
Total	230 (57.5%)	170 (42.5%)	400 (100%)

With regard to **Table 4**, in Kinshasa health structures, a statistically very significant difference was noted between radiologists who have knowledge of radiation protection standards compared to non-radiologists (P < 0.05).

Table 4. Distribution of surveyed radiologists versus non-radiologists according to knowledge of radiation protection standards in Kinshasa.

Respondents	Knowledge of health personnel on radiation protection standards		Total
	Sufficient	Insufficient	
Radiologist	88 (22%)	12 (3%)	100 (25%)
Non-radiologist	80 (20%)	220 (55%)	50 (75%)
Total	168 (42%)	232 (58%)	400 (100%)

According to **Table 5**, there is a statistically very significant difference between health professionals who know the radiation protection principle related to their category and those who do not (P < 0.05).

Table 5. Distribution of respondents according to knowledge of radiation protection principles in relation to their category in Kinshasa structures.

Respondents	Knowledge of healthcare personnel on radiation protection principles according to their category		Total
	Sufficient	Insufficient	
Radiologist	89 (22.2%)	11 (2.75%)	100 (25%)
Non-radiologist	200 (50%)	100 (25%)	300 (75%)
Total	289 (72.2%)	111 (27.7%)	400 (100%)

With regard to **Table 6**, concerning the analysis of knowledge of radiologist and non-radiologist health personnel on ICRP DRLs in Kinshasa structures, there is a statistically significant difference (P < 0.05).

Table 6. Distribution of respondents according to knowledge of ICRP DRLs in Kinshasa health structures.

Respondents	Knowledge of healthcare personnel on ICRP diagnostic reference levels		Total
	Sufficient	Insufficient	
Radiologist	10 (2.5%)	90 (22.5%)	100 (25%)
Non-radiologist	7 (1.7%)	293 (73.2%)	300 (75%)
Total	17 (4.2%)	383 (95.7%)	400 (100%)

With regard to Table 7, there is no statistically significant difference between radiologists and non-radiologists in their knowledge of the main source of artificial irradiation in Kinshasa health structures (P > 0.05).

Table 7. Distribution of respondents according to knowledge of the main source of artificial irradiation.

Respondents	Knowledge of healthcare personnel on the main source of artificial irradiation		Total
	Sufficient	Insufficient	
Radiologist	25 (6.25%)	75 (18.75%)	100 (32.8%)
Non-radiologist	60 (15%)	240 (60%)	300 (68.4%)
Total	90 (22.5%)	310 (77.5%)	400 (100%)

3.3. Contribution to Radiation Protection Optimization in Kinshasa Health Structures

- The majority of surveyed radiologist health personnel in Kinshasa province noted that more than 40% of requested radiology examinations are confirmed to be unjustified. As is the case throughout the DRC, to avoid frustrating patients who have already been reassured by the referring doctors or nurses about the justification for the examinations, radiology services find themselves obligated to examine them, rightly or wrongly.
- Also, all radiologist health personnel in Kinshasa do not know how to evaluate the degree of irradiation in their services. They attribute this major task to other bodies such as the Nuclear Studies Center of Kinshasa (CREN-K) and the National Commission for Protection against Ionizing Radiation (CNPRI), even though self-evaluation of services should be within their competencies.

These results indicate that capacity building is needed for practicing radiologist personnel, and a restructuring of the radiation protection program is necessary for health science students at higher education and university levels.

According to Table 8 relating to the analysis of the degree of contribution to radiation protection optimization in Kinshasa structures, there is a statistically significant difference between radiologists and other health personnel (P < 0.05).

Table 8. Distribution of health professionals according to their contribution to radiation protection with regard to appropriate principles.

Respondents	Contribution of healthcare personnel to the optimization of radiation protection		Total
	Negative	Positive	
Radiologist	40 (10%)	60 (15%)	100 (25%)
Non-radiologist	80 (20%)	220 (55%)	300 (75%)
Total	120 (30%)	280 (70%)	400 (100%)

According to **Table 9**, two out of the 23 surveyed radiology services in Kinshasa health structures were found to be irradiating for adults, which represents 9%.

According to **Table 10**, eleven out of the 23 surveyed radiology services in Kinshasa health structures were found to be highly irradiating, which represents 48%.

Table 9. Summary comparison between ICRP DRLs and dosimetric yields (ED/DRL) of radiology services in Kinshasa health structures for adults.

Kinshasa Health Structures	Means		T	IC à 95%	P
	FROM(NRD) HPGRB	NRD/ICRP			
CUK	4.2 mGy	8.54 mGy	−1.364	(−12.38 - 1.91)	0.222
HASC/kinshasa	4.72 mGy	8.54 mGy	−1.266	(−9.49 - 2.87)	0.246
CPP/Unikin	4.21 mGy	8.54 mGy	−1.157	(−11.12 - 2.47)	0.171
HPGR/Kin Ex.MamaYemo	2.24 mGy	8.54 mGy	−1.931	(−14.28 - 1.68)	0.102
HGR/Roi Bd1^{er}	10.22 mGy	8.54 mGy	0.507	(−6.44 - 9.81)	0.630
HGR/Ndjili	0.888 mGy	8.54 mGy	−1.97	(−17.1 - 1.82)	0.095
HGR/Kimbond	21.7 mGy	8.54 mGy	2.502	(0.31 - 28.02)	0.046
HGR/Matete	2.71 mGy	8.54 mGy	−1.544	(−15.06 - 3.41)	0.174
HGM/Nkokolo	11.9 mGy	8.54 mGy	0.583	(−10.96 - 17.8)	0.581
CH.Kimbaseke	10.4 mGy	8.54 mGy	0.939	(−14.28 - 1.68)	0.102
CH.Lisungi	3.52 mGy	8.54 mGy	−1.916	(−11.41 - 1.39)	0.104
CBM.Matonge	4.95 mGy	8.54 mGy	−1.062	(−11.8 - 4.68)	0.329
HGR/Bumbu	4.7 mGy	8.54 mGy	−0.987	(−13.37 - 5.68)	0.362
CNPP/Kinkole	1.06 mGy	8.54 mGy	−1.988	(−16.6 - 1.72)	0.094
CMMASS/Mab	2.18 mGy	8.54 mGy	−1.670	(−15.66 - 2.95)	0.146
CH/Kikimi/Nse	1.92 mGy	8.54 mGy	−1.931	(−14.28 - 1.68)	0.158
CH.Selembao	9.94 mGy	8.54 mGy	0.667	(−3.73 - 6.53)	0.530
HGR/M^{t} Amba	21.6 mGy	8.54 mGy	4.791	(6.40 - 19.79)	**0.003**
CLIN.NgaliemaI	12.3 mGy	8.54 mGy	1.659	(−1.80 - 9.40)	0.148
CLIN.NgaliemaII	1.1 mGy	8.54 mGy	−2.040	(−16.37 - 1.48)	0.087
HG.Kintambo	11.8 mGy	8.54 mGy	0.929	(−5.31 - 11.83)	0.389
CME/Ngaba	26.5 mGy	8.54 mGy	6.512	(11.3 - 25.24)	**0.001**
CLIN/Kinoise	1.91 mGy	8.54 mGy	−1.911	(−15.11 - 1.85)	0.105

Table 10. Summary comparison between ICRP DRLs and dosimetric yields (ED/DRL) of radiology services in Kinshasa health structures in pediatrics.

Kinshasa Health Structures	Means		T	IC à 95%	P
	FROM(NRD)/ HOSPITALS	NRD/ICRP			
CUK	1.05 mGy	0.225 mGy	3.979	(0.17 - 0.68)	**0.005**
HASC/kinshasa	1.087 mGy	0.225 mGy	3.424	(0.14 - 0.78)	**0.011**
CPP/Unikin	0.93 mGy	0.225 mGy	1.779	(−0.17 - 0.73)	0.119
HPGR/Kin Ex.MamaYemo	0.83 mGy	0.225 mGy	1.992	(−0.04 - 0.47)	0.087
HGR/Roi Bd1er	0.52 mGy	0.225 mGy	−0.537	(−0.51- 0.32)	0.608
HGR/Ndjili	0.64 mGy	0.225 mGy	0.134	(−0.33 - 0.37)	0.897
HGR/Kimbondo	0.95 mGy	0.225 mGy	1.929	(−0.07 - 0.72)	0.095
HGR/Matete	0.84 mGy	0.225 mGy	1.649	(−0.16 - 0.94)	0.143
HP/Kalembelemb	0.16 mGy	0.225 mGy	−2.820	(−0.83 - 0.073)	**0.026**
HGM/Nkokolo	5.32 mGy	0.225 mGy	7.692	(3.25 - 6.14)	**0.000**
CH.Kimbaseke	2.50 mGy	0.225 mGy	6.397	(1.18 - 2.57)	**0.000**
CH.Lisungi	1.17 mGy	0.225 mGy	2.129	(−0.61 - 1.16)	0.071
CBM.Matonge	3.02 mGy	0.225 mGy	6.045	(1.46 - 3.34)	**0.001**
HGR/Bumbu	0.43 mGy	0.225 mGy	−1.047	(−0.60 - 0.23)	0.330
CNPP/Kinkole	0.48 mGy	0.225 mGy	−0.694	(−0.61 - 0.33)	0.510
CMMASS/Mab	2.66 mGy	0.225 mGy	8.603	(1.48 - 2.60)	**0.000**
CH/Kikimi/Nse	1.087 mGy	0.225 mGy	2.694	(0.056 - 0.87)	0.031
CH.Selembao	1.57 mGy	0.225 mGy	1.409	(−0.64 - 2.55)	0.202
HGR/Mt Amba	4.85 mGy	0.225 mGy	14.589	(3.54 - 4.91)	**0.000**
CLIN.NgaliemaI	7.01 mGy	0.225 mGy	5.659	(3.67 - 9.10)	**0.001**
CLIN.NgaliemaII	7.01 mGy	0.225 mGy	5.569	(3.67- 9.10)	**0.001**
HG.Kintambo	0.51 mGy	0.225 mGy	−0.810	(−0.43 - 0.211)	0.445
CME/Ngaba	10.4 mGy	0.225 mGy	23.305	(11.3 - 25.24)	**0.000**
CLIN/Kinoise	1.91 mGy	0.225 mGy	1.397	(−0.24 - 0.94)	0.205

4. Discussion of Results and Proposals for Didactic and Pedagogical Remediation

4.1. Discussion of Results

Many of the surveyed individuals from health structures in Kinshasa were non-radiologists, accounting for 75%, and the vast majority of surveyed health structures in Kinshasa were from the public sector, at 65.2% (**Table 1** and **Table 2**). These results are similar to those found by Bope *et al.* in their research on evaluating the knowledge of radiologist versus non-radiologist health personnel on radiation protection optimization conducted in Bukavu, South Kivu, DRC [10].

In Kinshasa health structures, there is a statistically significant difference between radiologist health personnel who have knowledge about radiation effects compared to those of other categories ($P < 0.05$)

In view of **Table 4**, in the health facilities of Kinshasa, a statistically very significant difference was noted between radiologists with knowledge of radiation protection standards compared to non-radiologists ($P < 0.05$). These results do not align with those of Brise H. *et al.* in their article: "Recording the exposure dose in radiological reports: why? how?" [11] [12]

However, these data corroborate those of Bope Kwete M *et al.* (2014) in their article [13]. There is also a statistically very significant difference between health professionals who know the radiation protection principles related to their category and those who do not. Similarly, regarding the analysis of knowledge of radiologist and non-radiologist health personnel on ICRP DRLs in Kinshasa structures, there is a statistically significant difference ($P > 0.05$).

Although radiologists have knowledge, practical implementation poses a problem for all categories of personnel. This situation is likely due to pedagogical and didactic deficits recorded during initial training, which is why we have proposed related remediation to address this lack of know-how in future health personnel in Kinshasa hospitals.

Both surveyed radiologists and non-radiologists are unaware of the main source of artificial irradiation. Regarding the analysis of the degree of contribution to radiation protection optimization in Kinshasa structures, there is a statistically significant difference between radiologists and other health personnel ($P < 0.05$). Two out of 23 surveyed radiology services in Kinshasa health structures were found to be irradiating for adults (9%), and eleven out of 23 surveyed radiology services were found to be highly irradiating for children (48%). The pediatric population is more sensitive to radiation exposure than adults. This increased sensitivity varies with age, with younger individuals at higher risk [14]. Scientific studies have also shown that the occurrence of radiogenic tumors in children varies more than in adults and depends on the type of tumor, the child's age, and age at exposure. These studies on radiosensitivity differences between children and adults have shown that children are more sensitive to developing thyroid, brain, skin, and breast cancers, as well as leukemias [15]-[17].

The majority of surveyed radiologist health personnel in Kinshasa province noted that more than 40% of requested radiology examinations are confirmed to be unjustified. Like those in South Kivu and Kongo Central, to avoid frustrating patients who have already been reassured by referring doctors or nurses about the justification for the examinations, they feel obligated to examine them, rightly or wrongly. Also, all radiologist health personnel in Kinshasa do not know how to evaluate the degree of irradiation in their services. They attribute this major task to other bodies such as the Nuclear Studies Center of Kinshasa (CREN-K) and the National Commission for Protection against Ionizing Radiation (CNPRI), even though self-evaluation of services should be within their competencies.

These results indicate that capacity building is needed for practicing radiologist personnel, but especially a restructuring of the radiation protection program at the university level, incorporating aspects related to dosimetric evaluation. Pedagogical and didactic remediation at higher education and university levels are also essential to enable health science students, future health personnel, to acquire the knowledge and skills required for optimizing patient and environmental safety.

4.2. Proposals for Educational and Didactic Remediation

To teach radiation protection, it is essential to adopt appropriate educational and didactic strategies to facilitate understanding and ensure the integration of good practices. Here are some proposals [17]-[19]:

1) Early and progressive integration of radiation protection

- Introduce radiation protection from the beginning of medical training: introduce students to the basics of radiation physics, their biological effects, and the fundamental principles of radiation protection (justification, optimization, and dose limitation)
- Progressiveness: increase the complexity of concepts according to the evolution of students' knowledge

2) Interactive educational approaches

- Simulation and serious issues: use radiology simulators that integrate realistic scenarios highlighting the impacts of decisions on radiation exposure
- Case studies: analyze radiological incidents to (identify errors and discuss preventive measures
- Work in small groups: promote collaborative learning through practical workshops

3) Use of digital tools

- Applications and platforms: offer interactive modules to learn dosimetry; protocol optimization; and radiation protection standards
- Virtual reality: simulate medical imaging environments to learn how to handle equipment while respecting safety standards

4) Practical and contextualized training

- Supervised clinical internships: allow students to apply their knowledge in radiation protection under the supervision of experts
- Technical workshops: train in the correct use of radiological equipment (collimation, parameters, exposure, use of lead screens, etc.)
- Mock audits: organize mock assessments of radiological practices to raise awareness of the importance of compliance with protocols

5) Reinforcement of regulatory and ethical aspects

- Legislative framework courses: teach international and local regulations on radiation protection (IAEA standards, European directives, etc.)

- Continuous awareness and certification: offer regular tests to identify gaps and reinforce acquired knowledge
- Certification simulations: prepare students for official exams with exercises focused on radiation protection
- Continuous training: encourage regular updating of radiation protection knowledge even after initial certification

6) Formative assessments

- Formative assessments: offer regular tests to identify gaps and reinforce acquired knowledge
- Certification simulations: prepare students for official exams with exercises focused on radiation protection
- Continuing education: encourage regular updating of radiation protection knowledge even after initial certification

7) Promoting safety culture

- Conference and seminars: invite radiation protection experts to share their experiences
- Encourage feedback: build a climate of trust to report radiation protection incidents or errors
- Team awareness: integrate nurse technicians and doctors into common programs for an interdisciplinary approach

8) Expected results

These combined strategies will produce competent radiologists, aware of the risks associated with ionizing radiation; and capable of making informed decisions to optimize the safety of patients, medical staff and the public.

5. Conclusion

According to WHO, there is no medicine without imaging, and we add that there is no medicine without secure and reassuring imaging. This research has given us the opportunity to observe that radiologist and non-radiologist health personnel, although having some knowledge of radiation protection, do not sufficiently observe the related standards and principles in conventional radiology for maximizing patient and environmental protection. To enable health personnel to acquire the required knowledge and skills to help them make informed decisions regarding radiation protection for the optimization of radiological safety, pedagogical and didactic remediations in radiation protection teaching at higher and university levels have been proposed.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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