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Diagnostic Reference Levels, Protection of Patients and the Environment against Harmful Effects of X-Rays: Practice of Pediatric Radiology in Six General Reference Hospitals of the Kongo Central Province, DRC

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Abstract

The purpose of this research was to evaluate radiological safety in pediatric radiology in hospitals in the Kongo Central province of the DRC. To this end, we surveyed a convenience sample of 50 health professionals, including 10 radiologists working in the hospitals covered by the survey, to assess the practice of pediatric radiology and the degree of compliance with radiation protection principles for the safety of children and the environment. We collected radiophysical parameters to calculate entrance doses in pediatric radiology in radiology departments to determine the dosimetric level by comparison with the diagnostic reference levels of the International Commission on Radiological Protection (ICRP). All in all, we found that in Kongo Central in the DRC, many health personnel surveyed reported that more than 30% of requested radiological examinations are not justified. Also, after comparing the entrance doses produced in the surveyed departments with those of the International Commission on Radiological Protection (ICRP), a statistically significant difference was found in pediatric radiology between the average doses in five out of six surveyed departments and those of the ICRP. Therefore, almost all of the surveyed departments were found to be highly irradiating in children, while excessive X-ray irradiation in children can have significant effects due to their increased sensitivity to radiation. Among the risks are: increased cancer risks, damage to developing cells, potential genetic effects, and neurological effects. This is why support for implementing radiation protection principles is a necessity to promote the safety of patients and the environment against the harmful effects of X-rays in conventional radiology.

Keywords

Diagnostic Reference Levels (DRLs), Radiation Protection, Environment and Pediatric Radiology

1. Introduction

X-rays, developed in the late 19th century, were first demonstrated by Roentgen to be able to image the skeleton on photographic plates. The applications of radiation in medicine, industry, agriculture, and research rapidly expanded during the 20th century [1]. Nuclear weapons tests, routine industrial releases, and industrial accidents have introduced artificial radioactivity into the environment. However, the use of radiation in medicine is now the primary source of artificial exposure [2].

Radiation protection is an important element of overall patient and environmental safety. Equipment problems, process failures, and human errors in healthcare delivery can compromise safety. It is an inseparable component of professional responsibility in healthcare [3].

Irradiation remains a frequent and concerning cause of serious adverse events occurring worldwide. At Chernobyl, about 1800 thyroid cancers were observed in children living in territories near the power plant [1] [4].

Each year, between 120,000 to 190,000 serious, preventable adverse events occur during hospitalization, and between 700,000 to 1,100,000 admissions to healthcare facilities are due to a serious adverse event related to irradiation [5].

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) [4] [6].

The number of radiological procedures is steadily increasing by about 20% per year. Individual and collective doses are increasing faster than the number of procedures performed. These doses for the same procedure can vary by a factor of 1 to 100 depending on the centers, equipment, teams, and countries. It is estimated that if 10,000 children each received genital irradiation of 100 roentgen, there could be 75 cases of thyroid cancer, 240 cases of other cancers, and 40 cases of leukemia. 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, and 13 years of life lost per death related to thyroid cancer [6] [7].

In the Democratic Republic of Congo, radiological equipment is being distributed day by day in public general reference hospitals as well as in private facilities, which would increase the extent of radioactivity throughout the country [8].

In Kongo Central province in general, and particularly in the cities of Matadi, Boma, and Moanda, several radiology services are scattered throughout these cities in public and private health facilities. Most of them are run by personnel who have not received complete relevant training.

Still, in Kongo Central, out of 100% of requested radiological examinations, 50% come from pediatrics. And as tissues develop rapidly in children and sensitive organs are closer to the part to be x-rayed, children should be subject to better and more effective protection than adults.

The objective of this study was to evaluate the risks incurred by children, health professionals, and the environment against the harmful effects of X-rays during their use in radiodiagnosis in hospitals in Kongo Central in the DRC.

To do this, it was necessary to:

- Globally evaluate the level of observation of radiation protection principles by radiologist and non-radiologist health personnel.
- Collect radiophysical parameters used specifically in pediatric radiology.
- Calculate the entrance doses produced in these services during radiological examinations in children.
- Compare these doses with the dose reference levels of the International Commission on Radiological Protection (ICRP).

2. Materials and Methods

2.1. Type of Study

We conducted a cross-sectional study on radiological safety and the practice of pediatric radiology in general reference hospitals in Kongo Central Province in the DRC.

2.2. Site and Period of Study

Our investigation sites consisted of six general reference hospitals in Kongo Central province; namely the General Reference Hospitals of Matadi, Boma, Moanda, Kisantu, Luozi, and Kasangulu. The study was conducted over a period of October to April 2024.

2.3. Target Population

Radiologist and non-radiologist health professionals working in the health facilities concerned by the study constituted our target population.

2.4. Sampling

We surveyed a convenience sample of 50 health professionals including 10 radiologists working in the six general reference hospitals concerned by the survey; namely: Matadi GRH, Boma GH, Moanda GH, Kisantu GH, Luozi GH, and

Kasangulu GH. A questionnaire related to the evaluation of radiological safety in pediatric radiology was submitted to them. We used weighted stratified sampling to determine the number of health professionals to survey by category (Radiologist or non-radiologist).

2.5. Inclusion Criteria

- Be a radiologist or non-radiologist health professional.
- Be an effective staff member of the hospitals to be surveyed, agree to answer our questions and be present on the days scheduled for the survey.

2.6. Data Collection Techniques

For this study, the techniques used for data collection are face-to-face interviews using a semi-open questionnaire and participant observation.

2.7. Parameters Studied

Except for general aspects relating to the observance of radiation protection principles by all categories of health professionals for the safety of patients and the environment; the following parameters were the subject of our investigations for the eight examinations on the list of the International Commission on Radiological Protection in pediatrics: X-ray penetration (voltage in kilovolts), focus-film distance (FFD in cm); X-ray quantity in milliampere-seconds (MAS) and entrance surface dose. The entrance surface dose for each radiology department was calculated based on the above radiophysical parameters of the pediatric radiology examination protocol using the following formula:

$$\mathrm{DE} = 0.15 * (\mathrm{U}/100)^2 * \mathrm{Q} * (100/\mathrm{FFD})^2$$ [9].

where:

U is the high voltage in KV

Q is the charge in MAS

FFD is the focus-film distance

2.8. Statistical Calculations

The Student's t-test was useful to us as it allowed us to compare means to see if the difference between the mean doses of the surveyed hospitals and those of the International Commission on Radiological Protection is statistically significant or not. The chi-square test also allowed us to analyze the proportions between health personnel who observe radiation protection principles and those who do not.

2.9. Expected Impact

The results of this study will allow us to consider continuing education or capacity building of health personnel on radiation protection on the one hand, and on the other hand, to readjust the radiation protection course program in initial training to perpetuate radiological safety for maximizing the protection of patients and the environment against the harmful effects of X-rays.

3. Results

3.1. Categories of Respondents and Status of Health Facilities in Kongo Central

Table 1 informs us that many among the health personnel of the surveyed health structures in Kongo Central were non-radiologists, namely 80%.

Table 1. Distribution of respondents by professional category.

Respondents	Number	%
Radiologists	10	20
Non radiologists	40	80
Total	50	100

Table 2 indicates that a large number of the surveyed health structures in Kongo Central were from the public sector, namely (83.3%).

Table 2. Distribution according to the status of the surveyed health establishments.

Health establishments	Number	%
State-owned	5	83.3
Faith-based	1	16.6
Total	6	100

3.2. Opinions of Health Personnel in Kongo Central on the Justification of Radiological Examinations in Children

Looking at Table 3, the vast majority of radiology personnel said that a large number of radiological examinations prescribed for children are not justified. Still according to this table, in the health structures of Kongo Central, there is a statistically non-significant difference between radiology health personnel who declared the non-justification of radiological examinations prescribed for children compared to those of other categories ($p \le 0.05$).

Table 3. Distribution of surveyed radiologists versus non-radiologists in Kongo Central according to their opinion on the justification of radiological examinations prescribed for children.

Respondents	Justification of radiological examinations in pediatric radiology		Total
	Non justified	Justified	
Radiologist	8 (16%)	2 (4%)	10 (20%)
Non radiologist	21 (42%)	19 (38%)	40 (80%)
Total	28 (56%)	22 (44%)	50 (100%)

According to Table 4, the vast majority of radiology health personnel emphasized that more than 30% of radiological examinations prescribed for children prove to be unjustified. Also, this same table shows that the difference is not statistically significant between the extent of unjustified examinations reported by radiologists and that reported by non-radiologists ($p \geq 0.05$).

Table 4. Distribution of surveyed health personnel in Kongo Central according to the extent of unjustified radiological examinations prescribed for children in hospitals in Kongo Central, DRC.

Respondents	The extent of unjustified radiological examinations prescribed for children in hospitals in Kongo Central, DRC		Total
	1% - 30%	Plus de 30%	
Radiologists	1 (10%)	9 (90%)	10 (100%)
Non radiologists	1 (2.5%)	39 (97.5%)	40 (100%)
Total	2 (4%)	48 (96%)	50 (100%)

3.3. Contribution to the Optimization of Radiation Protection in Health Establishments in Kongo Central

According to Table 5, relating to the analysis of the level of contribution to the optimization of radiation protection in pediatric radiology in health structures of Kongo Central, there is a statistically significant difference between radiologists and other health personnel ($p \leq 0.05$).

Table 5. Distribution of health professionals according to their contribution to radiation protection with regard to appropriate principles in pediatric radiology.

Respondents	Contribution of health personnel to the optimization of radiation protection in pediatric radiology		Total
	Positive	Negative	
Radiologistd	4 (8%)	6 (12%)	10 (20%)
Non-radiologists	1 (2%)	39 (78%)	40 (80%)
Total	5 (10%)	45 (90%)	50 (100%)

According to Table 6, there is a statistically significant difference between radiologists and other health personnel who have knowledge of dosimetric evaluation of the department in the practice of pediatric radiology and those who do not have related knowledge ($p \leq 0.05$).

Table 6. Distribution of health professionals according to their knowledge of dosimetric evaluation of the radiology department.

Respondents	Knowledge of dosimetric evaluation of the radiology department		Total
	Yes	No	
Radiologist	4 (8%)	6 (12%)	10 (20%)
Non radiologist	1 (2%)	39 (78%)	40 (80%)
Total	5 (10%)	45 (90%)	50 (100%)

3.4. Comparison of Entrance Surface Doses from Surveyed Health Establishments in Kongo Central with the Diagnostic Reference Levels (DRLs/ESD) of the ICRP for Some Common Examinations

According to Table 7, comparing the DRLs/ESDs of the General Hospital of Massa in Kasangulu with the DRLs/ESDs of the ICRP in pediatrics, there is a statistically non-significant difference in means ($t > 0.05$). As such, the department is less irradiating for children at GRH/Massa.

Table 7. Comparison of entrance surface doses (ESD) from the general reference hospital of Massa in Kasangulu (GRH/Massa/Kasangulu) with the diagnostic reference levels of the international commission on radiological protection in pediatrics.

EXAMINATION	AGE	FROM/HGR/MASSA/ KASANGULU/PED.	NRD(DE)/CIPR/ PED.
Chest face AP	0 - 1 year	0.6	0.08
Chest face PA	5 years	0.5	0.1
Chest profile	5 years	1.1	0.2
Skull face PA	5 years	0.4	1.5
Skull profile	5 years	0.6	1
Pelvis AP	0 - 1 year	0.6	0.2
Pelvis AP	5 years	0.6	0.9
ASP	5 years	1.1	1

According to Table 8, there is a statistically very significant difference in means between the DRLs/ESDs of the General Hospital of Boma and the DRLs/ESDs of the ICRP in pediatrics ($p = 0.05$). Therefore, the radiology department of the General Hospital of Boma is highly irradiating in pediatrics.

Table 9 shows that there is a statistically very significant difference in means between the DRLs/ESDs of the General Hospital of Moanda and the DRLs/ESDs of the ICRP in pediatrics. Thus, the department is highly irradiating in pediatrics ($p = 0.05$).

Table 8. Comparison of entrance surface doses (ESD) from the general hospital of boma with the diagnostic reference levels of the international commission on radiological protection in pediatrics.

EXAMINATIONS	AGE	FROM/HG.DE BOMA/PED.	NRD(DE)/CIPR/ PED.
Chest face AP	0 - 1 year	0.4	0.08
Chest face PA	5 years	0.8	0.1
Chest profile	5 years	1.5	0.2
Skull face PA	5 years	2.7	1.5
Skull profile	5 years	2.7	1
Pelvis AP	0 - 1 year	3	0.2
Pelvis AP	5 years	3	0.9
ASP	5 years	3	1

Table 9. Comparison of entrance surface doses (ESD) from the general hospital of Moanda (GRH/MUANDA) with the diagnostic reference levels of the international commission on radiological protection.

EXAMINATION	AGE	FROM/HGR/ MOANDA/PED.	NRD(DE)/CIPR/ PED.
Chest face AP	0 - 1 year	4.03	0.08
Chest face PA	5 years	6	0.1
Chest profile	5 years	4.49	0.2
Skull face PA	5 years	7.04	1.5
Skull profile	5 years	7.04	1
Pelvis AP	0 - 1 year	6.53	0.2
Pelvis AP	5 years	6.53	0.9
ASP	5 years	7.5	1

According to Table 10, there is a statistically significant difference in means between the DRLs/ESDs/PED. of the General Reference Hospital of Kisantu (GRH/KISANTU) in Kongo Central and the DRLs/ESDs/PED. of the ICRP in pediatrics ($p < 0.05$). Consequently, the department is irradiating for children at the General Reference Hospital of Kisantu in Kongo Central.

According to Table 11, there is a statistically significant difference in means between the DRLs/ESDs/PED. of the General Reference Hospital of Luozi in Kongo Central and the DRLs/ESDs/PED. of the ICRP in pediatrics ($p < 0.05$). The department is highly irradiating for children at GRH/LUOZI.

According to Table 12, there is a statistically very significant difference in means between the DRLs/ESDs/PED. of the Provincial General Reference Hospital of Matadi and the DRLs/ESDs/PED. of the ICRP in pediatrics ($p > 0.05$). The department is highly irradiating for children at PGRH/Matadi.

Table 10. Comparison of entrance surface doses (ESD) from the general hospital of Kisantu (GRH/KISANTU) in Kongo Central with the diagnostic reference levels of the international commission on radiological protection in pediatrics.

EXAMINATION	AGE	FROM/HGR/ KISANTU/PED.	NRD(DE)/CIPR/ PED.
Chest face AP	0 - 1 year	3.41	0.08
Chest face PA	5 years	4.27	0.1
Chest profile	5 years	10.6	0.2
Skull face PA	5 years	28.5	1.5
Skull profile	5 years	32.8	1
Pelvis AP	0 - 1 year	3.4	0.2
Pelvis AP	5 years	6.63	0.9
ASP	5 years	4.9	1

Table 11. Comparison of entrance surface doses (ESD) from the general reference hospital of Luozi in Kongo Central with the diagnostic reference levels of the international commission on radiological protection in pediatrics.

EXAMINATIONS	AGE	FROM/HGR/ LUOZI/PED.	NRD(DE)/CIPR/ PED.
Chest face AP	0 - 1 year	1.51	0.08
Chest face PA	5 years	4.38	0.1
Chest profile	5 years	34.8	0.2
Skull face PA	5 years	34.8	1.5
Skull profile	5 years	20.5	1
Pelvis AP	0 - 1 year	26.6	0.2
Pelvis AP	5 years	16.4	0.9
ASP	5 years	16.4	1

Table 12. Comparison of entrance surface doses (ESD) from the provincial general reference hospital of Matadi with the diagnostic reference levels of the international commission on radiological protection in pediatrics.

EXAMINATIONS	AGE	FROM/HPGR/ MATADI/PED.	NRD(DE)/CIPR/ PED.
Chest face AP	0 - 1 year	0.39	0.08
Chest face PA	5 years	0.98	0.1
Chest profilee	5 years	3.16	0.2
Skull face PA	5 years	6.2	1.5
Skull profile	5 years	4.5	1
Pelvis AP	0 - 1 year	4.9	0.2
Pelvis AP	5 years	7.5	0.9
ASP	5 years	8.8	1

4. Discussion of Results

4.1. Status of Establishments and Categories of Health Professionals Surveyed

Many of our respondents were non-radiologists, namely 80%. This distribution was made possible thanks to stratified sampling weighted and proportional to the number of each category to avoid underestimating or overestimating one category or another. Also, 83% of the surveyed establishments were state-owned (**Table 1**, **Table 2**).

4.2. Opinions of Health Professionals on the Justification of Radiological Examinations Prescribed for Children in Hospitals in Kongo Central, DRC

In Kongo Central, many of the surveyed radiology health personnel reported that more than 30% of radiological examinations requested for children are not justified. To avoid frustrating patients who have already been reassured by requesting doctors or nurses, the services are obliged to receive them for examination, rightly or wrongly. These results corroborate those found by B. Bope Kwete M and others, in their article on evaluation of dosimetry in pediatric radiology in Bukavu, South Kivu in the DRC [10].

Also, the vast majority of radiology personnel openly stated that many radiological examinations prescribed for children are not justified. Still, according to this table, in the health structures of Kongo Central, there is a statistically non-significant difference between radiology health personnel who declared the non-justification of radiological examinations prescribed for children compared to those of other categories (**Table 3**). Looking at **Table 4**, the vast majority of radiology health personnel emphasized that more than 30% of radiological examinations prescribed for children prove to be unjustified. Also, this same table shows that the difference is not statistically significant between the extent of unjustified examinations reported by radiologists and that reported by non-radiologists ($P \geq 0.05$)

4.3. Contribution to the Optimization of Radiation Protection

The analysis of the degree of contribution to the optimization of radiation protection in pediatric radiology in health establishments in Kongo Central shows a statistically significant difference between radiologists and other health personnel; consequently, the contribution is negative in both categories. Also, a statistically significant difference was found between radiologists and other health personnel who have knowledge of dosimetric evaluation of the department in the practice of pediatric radiology and those who do not have related knowledge ($P > 0.05$). (**Table 5**, **Table 6**). These results are almost close to those found by B. Bope Kwete M and others in the article "Knowledge and practices of Health professionals on the Optimization of Radiation Protection in Diagnostic Radiology in Children and Adults in the General Referral Hospitals of Bukavu in South Kivu, DRC, JBM, 2022". But the bitter observation is that these results are very far from the recommendations of the ICRP [10].

4.4. Comparison of Entrance Doses of the International Commission on Radiological Protection with Entrance Doses Produced in Hospitals in Kongo Central Province, DRC

As can be seen, the various radiophysical indices varied according to the service and would also depend on the device but especially on the level of maintenance and regular control of the latter.

The General Hospital of Boma gave entrance surface doses in children that are significantly above the norm of the International Commission on Radiological Protection for the following examinations: pelvis 3mGy and lateral skull 2.7mGy. Also according to this same table, there is a statistically very significant difference in means between the DRLs/ESDs of the General Hospital of Boma and the DRLs/ESDs of the ICRP in pediatrics ($p < 0.05$). Thus, the radiology department of the General Hospital of Boma is highly irradiating in pediatrics (**Table 8**). Also, **Table 9** shows that there is a statistically very significant difference in means between the DRLs/ESDs of the General Hospital of Moanda and the DRLs/ESDs of the ICRP in pediatrics. Thus, the department is highly irradiating in pediatrics ($p > 0.05$).

According to **Table 10**, there is a statistically significant difference in means between the DRLs/ESDs/PED. of the General Reference Hospital of Kisantu (GRH/KISANTU) in Kongo Central and the DRLs/ESDs/PED. of the ICRP in pediatrics ($p < 0.05$). Consequently, the department is irradiating for children at the General Reference Hospital of Kisantu in Kongo Central. According to **Table 11**, there is a statistically significant difference in means between the DRLs/ESDs/PED. of the General Reference Hospital of Luozi in Kongo Central and the DRLs/ESDs/PED. of the ICRP in pediatrics ($p < 0.05$). The department is irradiating for children at GRH/LUOZI. According to **Table 12**, there is a statistically very significant difference in means between the DRLs/ESDs/PED. of the Provincial General Reference Hospital of Matadi and the DRLs/ESDs/PED. of the ICRP in pediatrics ($p < 0.05$). The department is highly irradiating for children at PGRH/Matadi. The results of **Table 10**, **Table 11**, and **Table 12** deviate significantly from the recommendations on good practices in radiation protection included in the PRP-HOM and IRSN report (2014) [11].

It is thanks to the various radiophysical indices (voltage in KV, charge in mAs, and focus-skin distance in cm) that we were able to calculate the entrance surface dose, which is equivalent to DRL, using the following formula: $0.15*(U/100)*Q*(100/DFP)$ in children (ICRP, 2011) [9] [12].

For our study, the brand of the devices matters little because our main concern remains the dose rate or entrance dose for each examination in adults as well as in pediatrics. DRLs are dosimetric indicators of the quality of practices allowing to identify situations requiring corrective action in pediatric radiology for the protection of children and the environment [12] [13]. The observation is generally deplorable because radiological safety is far from being ensured as five radiology departments out of the six surveyed are irradiating in children. The reasons for the observed deviation from the ICRP recommendations include equipment malfunctions due to the lack of regular quality control of radiological installations and insufficient training of professionals in radiation protection. One can realize the level of exposure of children and the environment. Due to their increased sensitivity to radiation and their longer remaining lifespan, children deserve special attention in the practice of pediatric radiology, although radiation protection should benefit patients of all ages, health professionals, and the environment given the high risks associated with ionizing radiation [14] [15].

5. Conclusion

This study allowed us to observe that five radiology departments of hospitals in Kongo Central do not comply with the standards of the International Commission on Radiological Protection. While children require extraordinary protection because of their increased sensitivity to radiation, the surveyed departments proved to be highly irradiating in pediatric radiology. Consequently, the protection of children and the environment against the harmful effects of X-rays is not sufficiently ensured. For this reason, it is necessary to recommend regular control of the units by the Regional Center for Nuclear Studies of Kinshasa (CREN-K) and the relentless support of the National Commission for Protection against Ionizing Radiation (CNPRI).

Conflicts of Interest

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

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