

Evaluation of Radiation Dose in Radiographic Procedures: Compliance with Brazilian and International Diagnostic Reference Levels (DRLs)

Comment [R11]: Brazil did not have DRL establish. There is only recommendations.

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ABSTRACT

Aims: The aim of this experimental study was to quantify the entrance surface air kerma ($K_{a,e}$) of X-ray beams in radiographic examinations, and the obtained values were compared with national and international Diagnostic Reference Levels (DRLs).

Place and Duration of Study: Sample: Department of Medical Physics and Radiology, Franciscan University (UFN), between June 2023 and August 2024.

Methodology: Initially, the main quality control (QC) tests were applied to characterize the radiographic equipment. During the evaluation of the X-ray beam, a dosimetric set was used, and for the same QC geometry, Air Kerma Rate (K_{AIR}) measurements were obtained to determine the output of the X-ray tube. Under the same conditions, a phantom without water and the same filled with water were used to determine the backscatter factor (BSF), which was then used to estimate the $K_{a,e}$ for the main radiographic examinations.

Results: The results of this study are consistent with other studies and identified the region/anatomy with the highest radiation exposure, highlighting the importance of its optimization and verifying that continued professional training should be integrated into best practices to ensure greater safety in procedures.

Conclusion: The comparative analysis between the $K_{a,e}$ values obtained in this study and the international DRLs revealed significant discrepancies in the radiation doses used in radiographic examinations. These differences highlight the need for continuous and careful evaluation of radiological practices, with a view to optimizing the dose and ensuring patient safety. The implementation of a radiation safety policy, based on local data and international references, together with the continuous training of professionals, is essential to promote the optimization of radiographic protocols. The relationship between $K_{a,e}$ and PKA values suggested in this study opens up new perspectives for a more accurate assessment of patient exposure. In summary, dose optimization in radiology requires a multidisciplinary approach and collaboration between various professionals in the field.

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1. INTRODUCTION

Diagnostic Reference Levels (DRLs) are reference values established by the International Commission on Radiological Protection (ICRP) for the amount of radiation used in imaging exams, such as radiography and computed tomography. These values serve as a benchmark to assess whether the radiation dose applied in an exam falls within an acceptable range, thereby contributing to the safety of both patients and healthcare professionals, as exposure to ionizing radiation, even at low doses, can pose health risks [1].

DRLs are expressed in units of mGy (milligrays), representing the radiation energy absorbed per unit mass (SI: $J \cdot kg^{-1}$). The "DRL Value" refers to a national arbitrary value for a specific DRL quantity, set at the 75th percentile of the median distribution across various DRL

Comment [R16]: DRL quantities assess the amount of ionising radiation used for a medical imaging procedure, not absorbed dose to a patient or organ. The one exception is mammography, for which D_0 may be used. Units: CTDIvol (mGy) and DLP (mGy.cm); PKA in $mGy \cdot cm^2$. In nuclear medicine is MBq

distributions. These indicators are recommended for identifying unusually high radiation doses in typical diagnostic radiology procedures [2]. However, exceeding a DRL does not necessarily imply that the exam is inadequate, nor does meeting a DRL guarantee that the practice is correct, as image quality (IQ) must also be considered [3].

Comment [R17]: Or unusually low

Recent studies, such as those by Alvarez et al. [4] and Diop et al. [5], highlight that DRL values account for various factors, including beam geometry, the anatomical region of the patient, tissue thickness, and the contribution of scattered radiation. The optimization of radiation protection, therefore, requires radiology professionals to balance dose and image quality, considering both DRLs and diagnostic needs. The application of the ALARA principle (As Low As Reasonably Achievable) is fundamental in this context, aiming to reduce the patient's radiation dose to the lowest possible level without compromising image quality.

To achieve this balance, it is necessary to adopt practices such as the appropriate selection of technical parameters, precise collimation, and dose reduction techniques, including filtration and image processing. In this regard, DRLs act as an essential tool for managing good radiological protection practices, provided they are properly understood and applied by radiology technicians and technologists [3].

Comment [R18]: Optimization process

This study aims to quantify the entrance surface dose of radiation to the patient during radiographic exams and compare the results obtained with the reference values established by the DRLs. Through this analysis, it seeks to contribute to the optimization of radiological procedures and ensure the safety of both patients and professionals in the field, promoting safer and more effective practices in radiology.

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2. MATERIAL AND METHODS

The study was conducted in the radiodiagnosis laboratory of the undergraduate programs in Radiology and Medical Physics, as part of the research carried out during the Quality Control and Radiodiagnosis courses at the Universidade Franciscana (UFN).

2.1. Equipments

Comment [R110]: Equipment

In this study, a radiographic equipment from Intecal brand and model MAAF was used, operating in a voltage range (kV) between 40 and 120 and current between 100 and 630 mA, coupled with a high-frequency generator. For the X-ray beam measurements, a dosimetry set from RADCAL, model 9015, calibrated in a reference laboratory, was used.

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2.2. Methodology

The research was conducted in 5 stages, which are represented in a flowchart in Figure 1.

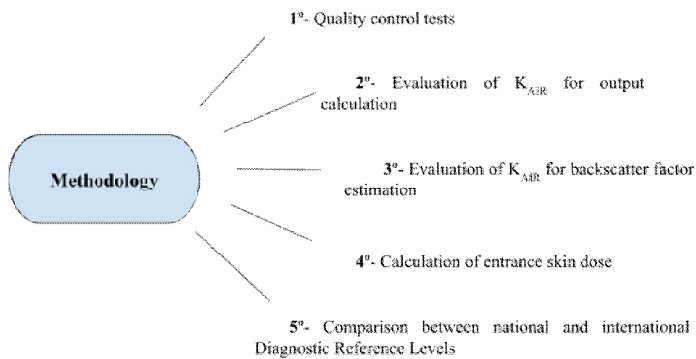


Fig. 1. Representation of the methodology in the form of a flowchart

2.3. Quality Control (QC) of Equipment

Before the start of the study, QC procedures for the radiographic equipment were carried out according to current guidelines and regulations [6,7] to ensure accurate and reliable results. Performing these procedures helps identify any technical failures and/or deviations in the operating parameters of the radiographic equipment.

2.4. Air KERMA Measurements

The test was conducted for nine selected kV values on the control panel of the radiographic equipment, using the same radiation field size (25 cm x 25 cm). In each stage, three readings were recorded for each kV value, while keeping the electric current (mA) and the product of current and time (mA.s) in the tube constant, as shown in Table 1.

Table 1. Selected electrical parameters for Air KERMA measurements

Electrical factors	Selected electrical parameters								
Voltage (kV)	40	50	60	70	81	90	102	109	120
Electric current (mA)	200								
mA.s	40								

To obtain the measurements of K_{AIR} , a dosimetry set and a phantom object (PO) consisting of a plastic box measuring 39 x 26.5 x 22.0 cm³ (length, width, and height, respectively) filled with water were used to simulate the patient on the table. A radiation field of 25 cm x 25 cm was opened, the distance between the tube focal point and the table was adjusted to 100 cm, and the Source-to-Image Distance (SID) used was 80 cm.

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Figure 2 depicts the X-ray tube, typical beam geometry for obtaining the typical radiographic examination, and identification of the main parameters used for medical exposure measurements.

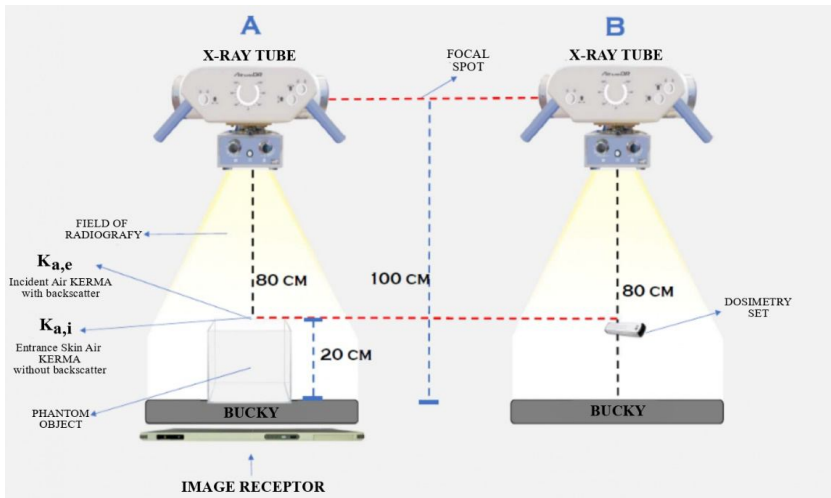


Fig. 2. Illustration of the geometry adopted for measurements of K_{AIR} , $K_{a,i}$, $K_{a,e}$, and backscatter (BSC)

During the radiographic examination, the X-ray beam consists partly of primary radiation, which penetrates a specific region of the patient and registers information of the internal anatomy of interest on the detector due to transmitted radiation. Additionally, it includes scattered radiation (backscatter), which contributes to the overall radiation dose received by the patient [8].

The output value was determined by the ratio between the average K_{AIR} readings obtained for each kV and mA.s value used. Furthermore, potential differences between the nominal and actual values of kV and mA.s across the entire operating range of the radiographic equipment were also checked, according to Equation 1.

$$Output = \frac{K_{AIR}}{mA.s} \quad (1)$$

2.5. Measurements of the Backscatter Factor (BSF)

To perform the measurement of the BSF, it was necessary to position and align the radiation detector appropriately, as illustrated in Figure 2(A), with the dome positioned over the table at 80 cm. For each kV value, three readings of K_{AIR} were taken, resulting in a total of 27 readings. Subsequently, the plastic box was filled with water to a thickness of 20 cm during the measurement, as depicted in Figure 2(B). Again, three readings of K_{AIR} were taken for each voltage value, totaling an additional 27 readings with the addition of water.

Due to the relevance of BSF in calculating $K_{a,e}$, it was decided to calculate the ratio between the average of K_{AIR} readings obtained with the dosimetry set with and without water, according to Equation 2:

$$BSF = \frac{K_{AIRwater}}{K_{AIRair}} \times \frac{\left[\frac{\mu_{tr}}{\rho}\right]_{water}}{\left[\frac{\mu_{tr}}{\rho}\right]_{air}} \quad (2)$$

where $K_{AIR_{water}}$ represents the reading on the surface of the phantom filled with water, $K_{AIR_{air}}$ the reading at the same position without water, and $\left[\frac{\mu_{tr}}{\rho}\right]$ refers to the mass energy transfer coefficient in water and air.

2.6. Evaluation of Entrance Skin Dose ($K_{a,e}$)

$K_{a,e}$ evaluations play a crucial role during QC tests to verify compliance with DRLs, ensuring that radiation doses used in diagnostic procedures are appropriate while minimizing adverse health effects. Furthermore, these evaluations are of utmost importance to enhance the quality and safety of radiological procedures, identifying opportunities to reduce radiation dose without compromising IQ or diagnostic information obtained [9].

According to ICRP Publication 135 of 2017 [1], the radiation metric used as a measure of DRLs should be easily measurable or available, such as $K_{a,e}$ in diagnostic radiology. In this study, $K_{a,e}$ was calculated through the assessment of output, determined in units of mGy/mA.s, at a FSD of 80 cm. According to Metaxas et al. [10], with this value, it should be corrected for the desired FSD using the inverse square law equation (Equation 3):

$$K_{a,e} (mGy) = Output \left(\frac{mGy}{mA.s} \right) \times \left(\frac{80}{FSD} \right)^2 \times (mA.s) \times BSF \quad (3)$$

where Output (mGy/mA.s) is the average of the K_{AIR} values obtained from the X-ray equipment, which increases with the square of the approach distance (FDD/FSD)², where FSD is represented by FDD minus the patient's thickness (in the region being radiographed) and depends on the protocol of each examination. Finally, due to the proportionality between tube output and mA.s, the last step to estimate $K_{a,e}$ is to multiply the X-ray tube output by the selected mA.s value on the control panel of the respective exposure technique and by the BSF.

2.7. Selection criteria

It was chosen to use the percentage deviation (D%) to compare the acquired values with the DRLs, according to equation 4:

$$D(\%) = \left[\left(\frac{\text{measured value of } K_{a,e}}{\text{reference value of DRL}} \right) - 1 \right] \times 100 \quad (4)$$

3. RESULTS AND DISCUSSION

Periodic assessment of the X-ray beam during Quality Control tests, conducted by Medical Physics professionals, possibly with the inclusion of other radiology professionals, can improve the safety of both patients and professionals, ensuring a more effective approach to radiological protection practices.

In Table 2, the types of tests applied for the evaluation of the radiographic equipment, along with the respective measured values and achieved results, are listed.

Table 2. Summary of Quality Control test results for the digital image radiographic equipment [6,7]

Comment [R113]: Where is the calculation of K_e for the patient sample?

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Test	Reproducibility		
	Exposure	Time	kVp
Obtained values	4.20%	1.72%	3.90%
Tolerance	≤10%	≤10%	≤5%
Result	Conform	Conform	Conform
Test	Accuracy		HVL (mmAl)
Obtained values	-6.48%	-5.02%	3.19
Tolerance	≤10%	≤10%	2.9
Result	Conform	Conform	Conform
Test	Output		
	Linearity		μGy/mA.s
Obtained values	5.68%		48.77
Tolerance	≤20%		-
Result	Conform		Conform

It can be observed in Table 2 that the constancy values of the radiographic equipment showed an error of less than 7% in the worst case, which is below the 10% accepted as the limit by legislation, ensuring good reproducibility of the equipment. The minimum limit for the half-value layer (HVL) at 80 kV is 2.9 mmAl, and since 3.19 mmAl was found, the results were considered acceptable in accordance with the current legislation [6,7].

Table 3 lists the selected values of voltage and the product of current by time (kV and mA.s) with the measured average values of KERMA in air and water, as well as the average calculated values of standard deviation (SD), output value (mGy/mA.s) and Backscatter Factor (BSF).

Table 3. Summary of Quality Control test results for the digital image radiographic equipment [6,7]

SELECTED VALUES		MEASURED VALUES				CALCULATED VALUES	
Current. time	Voltage	Readings in air		Readings in water		Output	BSF
(mA.s)	(kV)	Average (mGy)	SD	Average (mGy)	SD	(mGy/mA.s)	Air/Water
40	40	1.62	0.31%	1.75	0.06%	0.040	1.08
	50	2.93	0.06%	3.25	1.36%	0.073	1.11
	60	4.37	0.57%	4.93	0.60%	0.109	1.13
	70	5.93	0.49%	6.77	0.61%	0.148	1.14

81	7.61	0.83%	8.82	0.59%	0.190	1.16
90	8.95	0.87%	10.46	0.58%	0.224	1.17
102	10.88	4.04%	12.93	2.65%	0.272	1.19
109	12.10	3.06%	14.33	1.73%	0.302	1.18
120	13.85	3.61%	16.46	4.62%	0.346	1.19

As expected, it can be observed in Table 3 that the contribution of scattered radiation increases as the voltage (kV) increases, meaning that the increase in the primary beam energy results in an increased probability of scattered radiation occurrence [11]. This happens because, with higher energy, the radiation is less likely to be attenuated within the patient's body and more likely to escape, resulting in greater lateral scattering, backscattering, and forward scattering [12].

According to Diop et al. [5], after obtaining the K_{AIR} values for each kV and a fixed mA.s value in the spreadsheet, the output curve (output value) for the X-ray tube can be obtained. Other studies by Tompe&Sargar [13] highlighted that the intensity of the X-ray beam produced in a radiographic tube can be affected by the applied voltage due to two main factors: the number of electrons released and the energy of the photons.

Figure 3 graphically represents the output values (mGy/mA.s) as a function of the voltage selected on the X-ray equipment control panel.

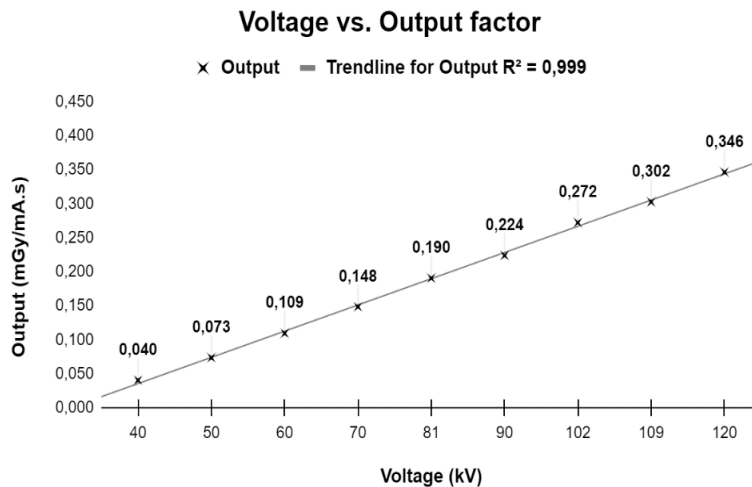


Fig. 3. The output curve of the radiographic tube

It is observed in the graph of Figure 3 that the linear upward trend of the radiographic tube's output (mGy/mA.s) as a function of kV. With the obtained values of yield (mGy/mA.s) and BSF for this study, it was possible to calculate the $K_{a,e}$ values for a typical individual using Equation 3, whose information on region, projection, and thickness was obtained according to ANVISA's technical manual for radiodiagnosis [14].

Comment [R116]: It is necessary to define the range of weight (60-70)kg, for example, but consider the parameters applied in a sample of at least 20 patients for each clinical indication. After that, a median of the values should be calculated.

If scattered radiation is detected by the image receptor, it affects the image and can be a significant cause of its degradation. Scattered radiation creates a grayscale in the image in areas that do not correspond to the anatomical projection, and this can significantly reduce the contrast in the radiograph [12].

Table 4 presents a comparison between the estimated $K_{a,e}$ values obtained in this study and the Reference Levels established by RDC 330/52 for different radiographic exams in various projections and body regions.

Table 4. Comparison of the $K_{a,e}$ estimate with the reference levels established by RDC 330/52 [6,7]

RADIOGRAPHIC EXAMINATION		TECHNIQUE			DOSIMETRY		
Region	Incidence	Thickness ^[a] (cm)	kV	mA.s	$K_{a,e}$ ^[b] (mGy)	DRLs ^[c] (mGy)	D%
Skull	AP	19	81	20	4.30	5	-14.00%
	LAT	15	70	20	2.99	3	-0.33%
Chest	PA	23	102	2	0.17	0.4	-57.50%
	LAT	32	120	5	0.60	1.4	-57.14%
Abdomen	AP	23	81	20	4.76	10	-52.40%
Pelvis	AP	23	81	20	4.76	10	-52.40%
	AP	23	81	25	5.95	10	-40.50%
Lumbar Spine	LAT	30	102	50	21.14	30	-29.53%
	LJ	20	70	40	15.78	40	-60.55%

^[a]Radiographic thicknesses, considering a typical adult patient (weight from 60 kg to 75 kg and height from 1.60 m to 1.75 m); ^[b] $K_{a,e}$ is considered the best indicator of deterministic effects, such as the death of a large number of cells, which can lead to tissue collapse, causing it to cease its functions in the organism; ^[c]Reference levels for radiographic diagnostic imaging, in terms of Entrance Surface Dose, for a typical adult patient.

When comparing the $K_{a,e}$ values obtained in this study with the DRLs established by RDC 330/52, we can observe a significant variation in many cases. For example, for the anteroposterior (AP) skull radiographic exam, the estimated $K_{a,e}$ value is 4.30 mGy, while the DRL established by RDC 330/52 is 5 mGy. This results in a discrepancy of -14.00% compared to the DRL.

These differences highlight the importance of monitoring and optimizing radiation doses used in radiographic procedures to ensure they comply with standards set by regulatory authorities. When $K_{a,e}$ values exceed DRLs, it may indicate excessive patient exposure to radiation, increasing the risk of adverse health effects.

In the case of the lateral (LAT) projection of the skull, the $K_{a,e}$ estimate resulted in a percentage deviation of -14%, indicating an underestimation compared to the established DRL. However, in other projections, such as the posteroanterior (PA) chest and lateral

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lumbar spine, there are significantly higher percentage deviations, indicating a substantial reduction in $K_{a,e}$ values compared to the established DRLs.

Suliman's studies [15] conducted a retrospective analysis through image analysis and found that the average $K_{a,e}$ (mGy) values for radiographic exams of PA chest, LAT chest, AP abdomen, AP pelvis, AP lumbar spine, and LAT lumbar spine were 0.13, 0.27, 0.70, 1.06, 2.33, and 4.18 mGy, respectively. Our study's results are consistent with chest findings; however, for the abdomen, pelvis, and lumbar spine regions, the values were higher.

Additionally, comparing the obtained doses with the DRLs emphasizes the importance of periodically reviewing and updating DRLs to ensure they align with current clinical practices and evolving imaging technologies. If doses consistently exceed recommended values, it may indicate a need to review radiological practices. This will help ensure patient safety and the quality of radiographic procedures, contributing to more effective and safer clinical practice.

These differences highlight the importance of monitoring and optimizing the radiation doses used in radiographic procedures to ensure compliance with the standards established by regulatory authorities (Figure 4). When $K_{a,e}$ values exceed DRLs, it may indicate excessive patient exposure to radiation, increasing the risk of adverse health effects.

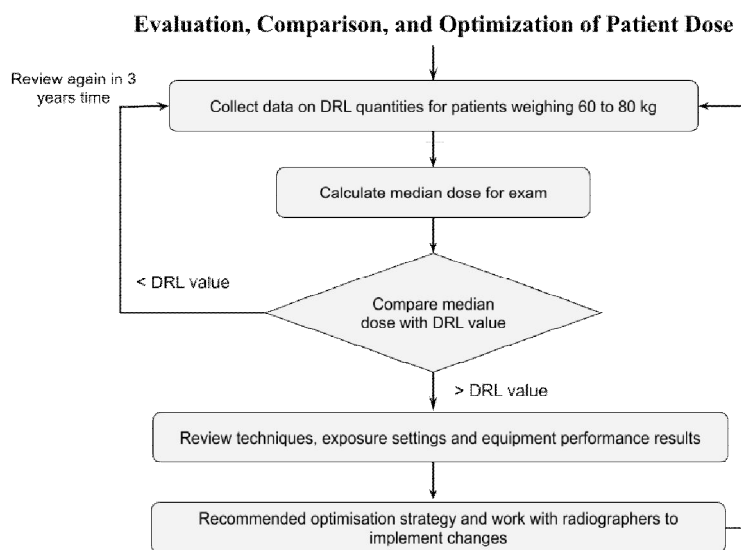


Fig. 4. Evaluation, comparison, and optimization of patient dose

Based on the presented results, it is recommended that healthcare institutions and competent authorities work together to review and update local DRLs, aligning them with the most current international references. Additionally, continuous training of radiology professionals can improve the proper use of imaging techniques, preventive maintenance of equipment, and the adoption of safe and effective practices.

We emphasize that DRLs are established to ensure that radiation doses in radiographic procedures are maintained at acceptable levels, guaranteeing appropriate exposure for diagnosis without compromising patient safety.

Table 5 offers a comparison between the estimated $K_{a,e}$ (mGy) values obtained in this study and the DRLs (mGy) adopted in other countries for various body regions in different radiographic projections.

Table 5. Comparison of the $K_{a,e}$ estimate with international reference levels $K_{a,e}$ (mGy) versus DRL (mGy)

Region (Incidence)	Our study	France ^[a]	United Kingdom ^[b]	Germany ^[c]	Sweden ^[d]	Italy ^[e]	Japan ^[f]
Skull (AP)	4.30	-	-	-	-	-	3
Skull (LAT)	2.99	-	-	-	-	-	2
Chest (PA)	0.17	0.3	0.15	0.3	0.3	0.4	0.3
Chest (LAT)	0.60	-	-	-	-	-	-
Abdomen (AP)	4.76	5	2	5	5	5	3
Pelvis (AP)	4.76	-	-	-	-	-	3
Lumbar (AP)	5.95	10	5	10	10	10	4
Lumbar (LAT)	21.14	30	11	30	30	30	11
Lumbar (LJ)	15.78	-	-	-	-	-	-

[a]Talbot; Rehel (2004), [b]Wall (2005), [c]Diop (2022), [d]Hart; Hillier; Wall (2009), [e]Compagnone; Pagan; Bergamini, (2005), [f]Yonekura (2015, p.12) [16-21].

The analysis of the results presented in Table 5, which relates the average $K_{a,e}$ values obtained in this study with international DRLs, shows variations compared to the DRLs adopted in other countries. For example, for the AP projection skull radiographic exam, the estimated $K_{a,e}$ value was 4.30 mGy, whereas in some countries like Japan, the corresponding DRL is 3.0 mGy. This indicates a discrepancy of approximately 30% compared to the Japanese standard. Similarly, for other body regions and different radiographic projections, such as the chest, abdomen, and lumbar spine, the $K_{a,e}$ values estimated in this study show variations relative to the DRLs adopted in different countries. For example, for the chest in the PA projection, the estimated $K_{a,e}$ value is 0.17 mGy, while in some countries like the United Kingdom, the corresponding DRL is 0.3 mGy.

These differences highlight the importance of evaluating and comparing locally obtained $K_{a,e}$ values with international reference standards. This allows the identification of areas where radiation doses may be above or below acceptable limits, enabling the implementation of corrective measures to ensure safe and effective radiological practice.

4. CONCLUSION

The assessment of radiation doses and the discussion of factors affecting the $K_{a,e}$ by Medical Physics professionals for other Radiology professionals are effective opportunities in clinical practice and can generate a safety policy for the optimization of radiographic

exams. This can include adjustments in imaging techniques, additional staff training, and the implementation of specific dose protocols.

A comparative analysis of national and international Diagnostic Reference Levels reveals significant variations in clinical practice, equipment, and methods for estimating $K_{a,e}$. Reviewing and updating national DRLs, in collaboration with healthcare institutions and competent authorities, is vital to ensure consistent radiological protection guidelines. Furthermore, the continuous training of radiology professionals is essential to ensure the proper use of imaging techniques and safe practices.

This study identifies projections and exams with high radiation doses, allowing the review and adjustment of protocols to optimize exposure and minimize risks to patients. Although DRLs are important, the quality of the images must also be evaluated. Moreover, future studies could relate $K_{a,e}$ values with Kerma Air Product (K_{AP}) values, which represent the product of the total air KERMA by the beam area, providing a more comprehensive assessment of the patient's total exposure.

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