ORIGINAL ARTICLE

Establishing Local Diagnostic Reference Levels for Pediatric Radiography: An In-Depth Analysis of Radiation Dose Variation Using Computed Radiography Systems in Morocco

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Abstract

Purpose: The Diagnostic Reference Levels (DRLs), first introduced by the International Commission on Radiological Protection (ICRP), function as a significant tool for evaluating medical imaging procedures and optimizing the doses of radiation administered to patients. Within this framework, this study aims to establish and analyze DRLs specific to pediatric radiography in the eastern region of Morocco.

Materials and Methods: The X-ray beam output and the standard backscatter factor value were utilized to estimate the entrance surface dose (ESD) for each patient, Data were collected on patient-specific parameters (age, height, weight, and BMI) and machine-specific parameters (kV, mAs, distance, and field sizes) for 200 patients. The control of the X-ray tube machine and the calculation of output parameters (mGy) were performed using the Piranha radiation dosimeter.

Results: For all data presented in the whisker box plot, their five-number summary was calculated. This provided the statistical distribution for the data. From the collected data, thorax, upper extremity, and lower extremity were the most conducted categories each contributing about 29.65%, 24.14%, and 22.07%. The lowest contribution was from the crane category at around 4.14%. The highest ESD for this LDRL was 0.028 mGy for the crane category and the lowest was 0.0067 mGy in the Lower Extremity category.

Conclusion: The third quartile ESD values have been set as the institutional DRLs, highlighting the need to adjust radiographic practices to minimize patient exposure and enhance safety.

Keywords: Diagnostic Reference Levels; Entrance Skin Dose; X Ray Radiography; Patient Safety.

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1. Introduction

The safeguarding of pediatric patients during radiographic examinations necessitates a meticulous approach to radiation dose management, especially given the enhanced sensitivity of children to ionizing radiation [1, 2]. Recent global statistics indicate a significant reliance on X-ray examinations in pediatric healthcare, spotlighting the imperative for optimized radiation safety protocols [3]. Despite the ubiquity of these procedures, the potential health risks associated [4] with excessive radiation exposure cannot be overstated, underscoring the need for advancements in imaging technologies that prioritize patient safety [5].

Computed Radiography (CR) systems emerge as a pivotal advancement in this context, offering a viable pathway to minimizing radiation doses while ensuring diagnostic precision. Comparative studies have consistently demonstrated the superior efficacy of CR systems in dose reduction [6], attributed to their advanced imaging capabilities and dose optimization features [7]. However, the adoption of such technologies varies widely, with certain regions lagging in the integration of these critical advancements into clinical practice [8-10].

The literature reveals a broad spectrum of research focusing on radiation dose management in pediatric radiography [11-13], yet there exists a notable paucity of studies specifically addressing the adoption and efficacy of CR systems in developing countries, including Morocco. This gap highlights a critical area for research, particularly in understanding the barriers to adopting CR technology and its potential impact on radiation safety in pediatric imaging [14, 15].

This study aims to fill this gap by providing a comprehensive analysis of radiation dose metrics in pediatric X-ray examinations using CR systems within a Moroccan context. This research not only contributes to the international discourse on pediatric radiation safety but also offers insight into the specific challenges and opportunities for improving radiographic practices in Morocco.

2. Materials and Methods

This research was conducted by analyzing dosimetric data collected from 200 pediatric patients who underwent six distinct types of radiographic examinations using a digital radiography system at a premier hospital in the eastern region of Morocco. This hospital, known for conducting the highest number of radiological examinations in the region, served as an ideal site for this study due to its significant patient volume and advanced radiographic technology.

2.1. Detector

The dosimetry data were obtained using the Piranha R16-2.3 dosimeter (Version 2018.2A, Firmware 4.2B) (Figure 1), renowned for its precision in calibrating X-ray machines and measuring their output. The dosimeter boasts a kVp measurement range of 35 to 160 kVp with an accuracy of ±1.5%, a dose measurement range from 15 nGy to 1000 Gy with a precision of ±5%, and a time measurement range of 0.1 ms to 2000 s, accurate to ±1% or ±0.5 ms, ensuring comprehensive and accurate dosimetry data for our study.

Figure 1. Si PIN photodiode, Piranha

2.2. Imaging System

The digital radiography system utilized for this study was provided by ITALRAY, installed at the hospital in 2018. This system was chosen for its advanced digital imaging capabilities, which are critical for achieving accurate and reliable dosimetric assessments in pediatric radiography.

2.3. Patient Cohort

The study population consisted of children ranging from 28 days to 16 years of age. The distribution of radiological examinations performed included chest, upper limb, and lower limb exams as the most prevalent, with skull examinations being the least common. Detailed records of each patient's age, sex, weight, and the specific type of examination conducted were meticulously maintained. Radiographic parameters such as tube potential (kVp), tube current (mA), exposure time (seconds), and focus-to-skin distance (FSD, in cm) were systematically recorded for each examination, providing a robust dataset for analysis.

Figure 2 graphically represents the distribution of the 200 patients according to the category of their X-ray examination. The chart highlights that chest examinations are the most frequent, accounting for 29% of all cases, demonstrating a significant focus on thoracic imaging within the facility. Conversely, head examinations comprise about 4% of the total, indicating a relatively lower frequency of cranial imaging.

2.4. Quality Assurance

Prior to the commencement of patient dose measurements, a comprehensive Quality Assurance (QA) testing protocol was rigorously applied to the X-ray machine. This testing was essential to ensure that all measured parameters, which are critical for accurately calculating skin dose, were performing within expected tolerances. The QA process involved assessing the kVp accuracy (Table 1), mA linearity, timer consistency, output coherence, beam alignment, and the congruence of optical and radiation fields, with all parameters demonstrating satisfactory correlation with one another.

Table 1. Tube voltage accuracy

Set (kV)	Tube voltage (kV)	kVp (%)	Machine accuracy (%)	Status
50	49.52	-1.0		
60	59.91	-0.2		
70	69.95	-0.1		
80	80.1	0.1		
90	90.7	0.8		
100	100.05	0.1	Pass	Pass
110	110.41	0.4		
120	120.91	0.8		

2.5. Estimation of Entrance Skin Dose (ESD)

The estimation of the Entrance Skin Dose (ESD) to patients is pivotal in evaluating the radiation risk during pediatric X-ray examinations. In this study, ESD was meticulously calculated using a refined equation that factors in the tube output, exposure parameters, and the universally recognized Backscatter Factor (BSF). For this study, BSF was

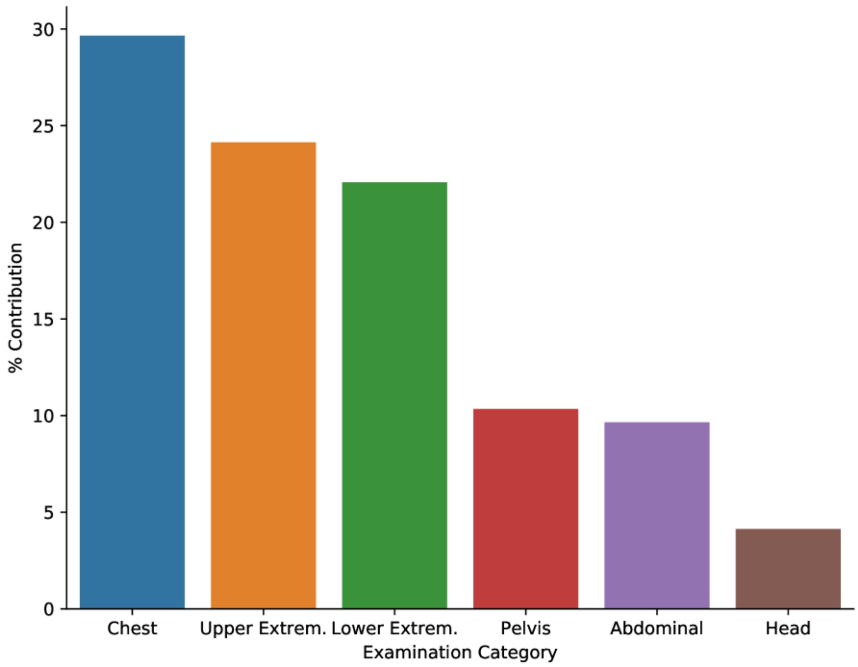

Figure 2. Distribution of the percentage contribution across six categories of hospital examinations

standardized at 1.35, acknowledging its variability between 1.2 to 1.5 in diagnostic radiography practices, to maintain consistency across measurements. The calculation of ESD was based on Equation 1 [16]:

$$ESD(mGy) = \frac{output(mGy)}{mAs} . kVp^2 . \frac{FDD^2}{FSD} . BSF \qquad (1)$$

where:

- **Tube Output** is measured in mGy, calibrated for various kVp settings to encompass the range typically employed in pediatric radiography, from 50 to 120 kVp, increasing by increments of 10 kVp. A fixed tube current-exposure time product (mAs) of 20 mAs was utilized, measured at a standard Focus-to-Detector Distance (FDD) of 100 cm, to simulate common clinical settings, the figure. The tube output was calculated using the formula in Equation 2 [16].

$$Output(mGy) = K \cdot kVp^n \cdot mAs \cdot \frac{1}{d^2} \qquad (2)$$

- FDD is focused on detector distance (cm).
- **FSD (Focus to Skin Distance)** is the distance from the X-ray tube's focal spot to the patient's skin, a critical parameter in dose calculation, influencing the spread of the X-ray beam and thus the dose received by the patient.
- **BSF (Back Scatter Factor)** accounts for the increase in measured dose due to backscatter radiation, which is significant in the pediatric patient population due to their smaller size.

This methodological approach allows for a comprehensive and precise estimation of ESD, facilitating a robust assessment of radiation doses received by pediatric patients. By standardizing BSF and meticulously calculating the tube output at various kVp settings, this study ensures an accurate representation of ESD across different types of radiographic examinations. Such detailed analysis is instrumental in establishing diagnostic reference levels (DRLs) and optimizing patient safety protocols in pediatric radiology.

3. Results

Our comprehensive analysis encompassed 200 pediatric patients undergoing six categories of X-ray examinations, yielding a rich dataset for statistical and dosimetric evaluation. The examination categories included abdominal, chest, head, lower extremity, pelvis, and upper extremity.

3.1. Statistical Insights

Figure 3 shows the variation of X-ray machine output (mGy/mAs) at various kVp settings ranging from 40–120 kVp at an increment of 10 kVp and 20 mAs at a fixed FDD of 100 cm. The results in Table 2 revealed significant variability in Entrance Skin Dose (ESD) across the examination types, with the head category registering the highest mean ESD of 0.0183 mGy, and the lower extremity category the lowest at 0.00563 mGy. Such disparities underscore the influence of examination type on radiation exposure, necessitating tailored dose optimization strategies.

A deeper statistical analysis, incorporating standard deviation and quartile values (Table 3), further delineated the distribution of ESD within each category. For instance, the chest category exhibited a broad range of doses (standard deviation: 0.00557 mGy), highlighting potential areas for dose reduction through optimized protocols. Conversely, the narrower distribution in the lower extremity category (standard deviation: 0.00244 mGy) suggests a more consistent application of dose optimization techniques.

3.2. Comparative Analysis

Comparing these findings with pediatric diagnostic radiology practices globally, it is evident that the observed ESD values align closely with international benchmarks, affirming the efficacy of the employed radiographic techniques. However, the variability in dose across examination types and the high standard deviation values in certain categories suggest opportunities for further dose reduction, aligning with the ALARA (As Low As Reasonably Achievable) principle.

3.3. Visual Enhancements

To enhance the clarity and accessibility of our findings, we have employed graphical representations in the form of box plots. Figure 4 displays the distribution of patient-specific parameters across six X-ray examination categories. These parameters include: (a) patient age in years, (b) patient height in meters, (c) body mass index (BMI), and (d) patient weight in kilograms. Figure 5, on the other hand, visualizes machine-specific parameters measured across the same six categories of X-ray examinations. These parameters encompass: (a) kilovoltage, (b) milliampere-seconds (mAs), (c) focus-to-skin distance in centimeters, (d) exposure time in milliseconds, and (e-f) field sizes in centimeters. These visual representations facilitate a comprehensive understanding of the variations and relationships between each parameter, providing insights into both patient demographics and machine utilization in different diagnostic contexts.

4. Discussion

This research aims to establish the local Diagnostic Reference Level (DRL) for pediatric radiography by analyzing the third quartile value of the Entrance Skin Dose (ESD).

Within this investigation, patient characteristics such as age, height, and weight demonstrate a relatively uniform distribution among various groups, displaying minor discrepancies according to the particular anatomical region being examined.

In the context of examination types - chest, abdomen, and pelvis - the third quartile values of ESD exhibit a comparable magnitude (0.0166mGy, 0.0133mGy, 0.137mGy) which can be attributed to the consistent employment of similar kilovoltages (66 kV, 60 kV, and 63 kV respectively). The mAs showed a slightly weak effect.

Notably, the head examination category portrays the third highest quartile of ESD in this study, primarily attributed to the employment of a higher

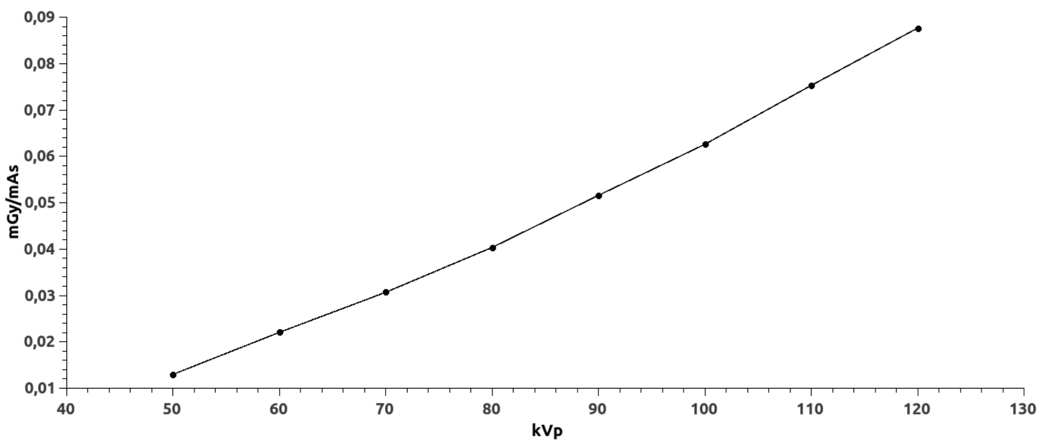

Figure 3. X-ray machine output mGy/mAs measured at various kVp stations

Table 2. ESD Statistics for Examination Categories

Examination Category	Mean	Std	Min	25%	50%	75%	Max
Abdominal	0.0108	0.0038	0.0059	0.0082	0.0102	0.0133	0.0187
Chest	0.0141	0.0056	0.0045	0.0105	0.014	0.0166	0.0279
Head	0.0183	0.0107	0.0095	0.0104	0.0131	0.0278	0.0319
Lower extremity	0.0056	0.0024	0.0031	0.0036	0.0051	0.0067	0.0141
Pelvis	0.0123	0.0036	0.0075	0.0102	0.0112	0.0137	0.0218
Upper extremity	0.0055	0.0021	0.0024	0.0041	0.0052	0.0069	0.0103

Table 3. The third quartile value (75th percentile) in relation to patients, machine parameters, and ESD across six categories of radiographic examinations

Category	Age (years)	Height (m)	Weight (kg)	BMI kg/m2	FSD cm	KV	MAS	T.exp (ms)	FDD (cm)	F.S "X" (cm)	F.S "Y" (cm)	ESD (mGy)
Head	9.50	1.20	30.50	22.22	108.50	66.75	6.55	19.50	129.75	29.25	33.50	0.03
Upper extremity	12.00	1.41	38.00	22.43	100.00	50.00	4.00	24.05	115.00	26.00	31.50	0.01
Chest	8.50	1.30	26.00	23.98	103.50	66.00	2.20	10.00	129.50	37.50	36.00	0.02
Abdominal	7.50	1.18	32.25	29.72	103.75	60.00	6.13	11.95	124.50	35.00	45.00	0.01
Pelvis	12.50	1.40	41.00	23.22	107.50	65.00	8.00	12.60	130.50	39.50	40.50	0.01
Lower extremity	10.00	1.42	41.00	22.96	103.50	50.00	4.10	28.80	122.00	26.00	31.75	0.01

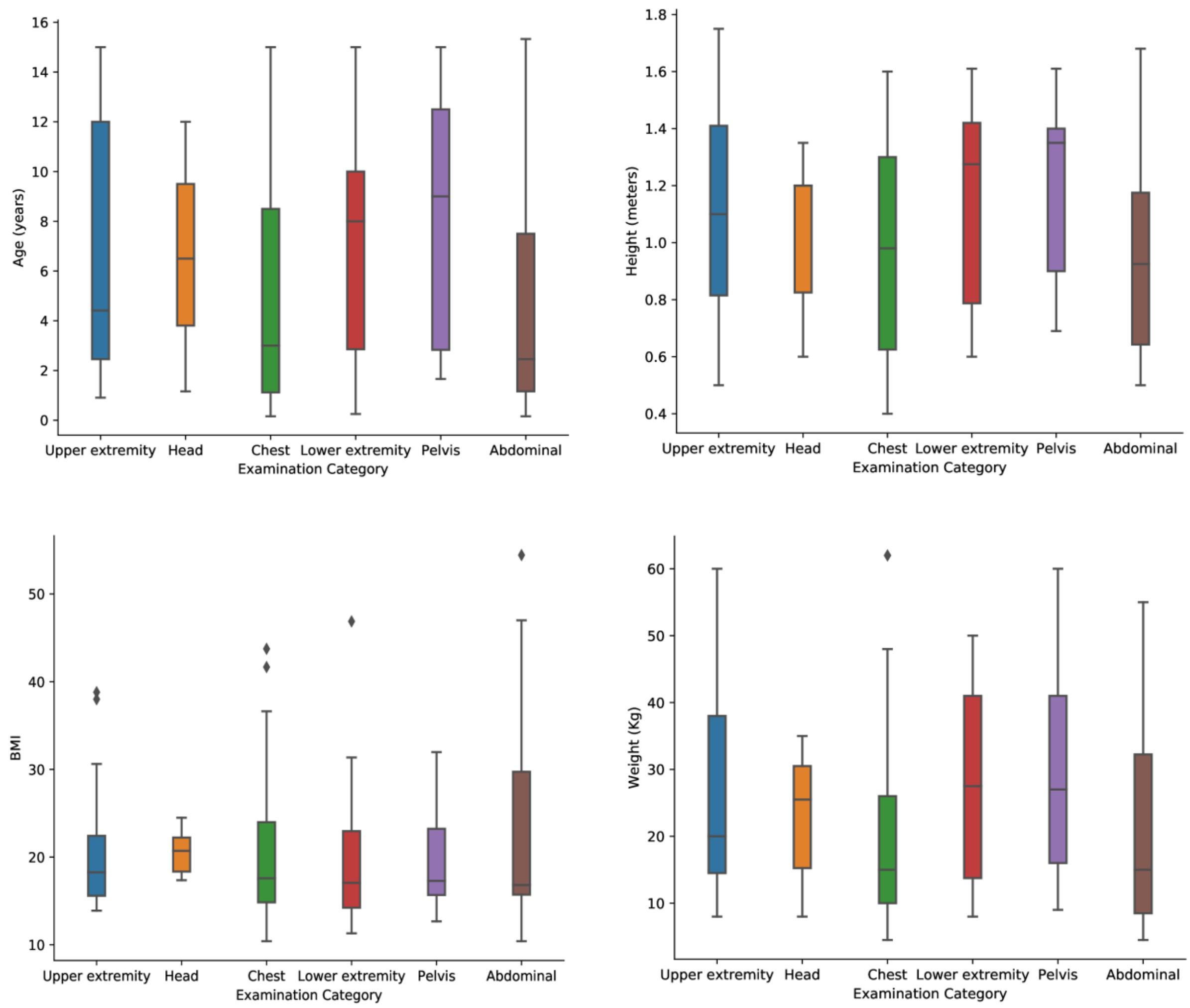

Figure 4. The Box plot related to examination category for: a) patient age (years), b) patient height (meter), c) BMI, and d) patient weight (kg)

kilovoltage (66 kV). In contrast, the upper and lower limb categories demonstrate the lowest third quartile values of ESD by virtue of the implementation of lower kilovoltages.

The size of the irradiation field in all tests indicated that it had no discernible impact on ESD.

The findings of this study elucidate significant variances in the Entrance Skin Dose (ESD) across different pediatric radiographic examinations, reflecting the inherent disparities in radiation exposure among the studied patient demographics and examination types. Such variability underscores the imperative for a nuanced approach to radiation dose optimization, particularly in pediatric populations where the risk of radiation-induced complications is substantively higher.

4.1. Broader Implications

Our analysis reveals that despite the advancements in computed radiography (CR) systems, opportunities for further dose optimization remain, especially in settings akin to Morocco. The integration of CR technology has indeed marked a significant stride towards reducing radiation exposure; however, the persistent variability in ESD points to the necessity for ongoing refinement of radiographic practices. These findings echo the global call for enhanced radiation protection protocols in pediatric radiology, advocating for a shift towards more individualized and context-specific dose management strategies.

In the Moroccan context, where resource constraints may impede the widespread adoption of the latest radiographic technologies, our study highlights the critical role of optimizing existing CR systems. By leveraging the capabilities of CR for dose reduction, healthcare facilities in Morocco and similar settings can make substantive progress towards safer pediatric radiography practices.

4.2. Recommendations for Practice

1. **Optimization of CR Settings**: Radiologists and technologists should be trained to utilize the full spectrum of dose optimization features available in CR systems, including the selection of appropriate exposure parameters tailored to the patient's size and the clinical indication.
2. **Dose Monitoring and Benchmarking**: Institutions should implement robust dose monitoring programs to track radiation exposure over time. Based on the data presented, facilities can establish Local Diagnostic Reference Levels (LDRLs) and benchmark their practices against these standards, identifying areas for improvement.
3. **Patient-Centric Approaches**: Embrace a patient-centric approach in dose management, considering patient-specific factors such as age, weight, and medical history in determining the optimal radiographic technique.
4. **Advanced Training and Education**: Continuous professional development programs should be instituted, focusing on the principles of radiation protection, the utilization of CR technology for dose reduction, and the interpretation of dose monitoring data.
5. **Research and Collaboration**: Encourage participation in national and international research initiatives aimed at reducing pediatric radiation doses. Collaboration across institutions can facilitate the sharing of best practices and innovations in dose optimization.

4.3. Visual Enhancements

The incorporation of graphical representations such as dose distribution histograms and scatter plots correlating patient demographics with ESD can significantly aid in visualizing the impact of various factors on radiation exposure. Such visual aids not only augment the comprehensibility of the findings but also provide a compelling narrative for the importance of dose optimization.

5. Conclusion

This investigation highlights the critical variability in radiation doses administered during pediatric X-ray examinations, underscoring the need for individualized dose management strategies. By establishing the 75th percentile of Entrance Skin Dose (ESD) values as Local Diagnostic Reference Levels (LDRLs), our study contributes to optimizing radiation safety protocols in pediatric radiology. The focused use of a single radiographic system has allowed for a precise analysis, reinforcing the significance of tailored approaches to radiation dose optimization. Ultimately, our findings advocate for enhanced patient safety measures, advocating for evidence-based adjustments to radiographic practices to safeguard the vulnerable pediatric population.

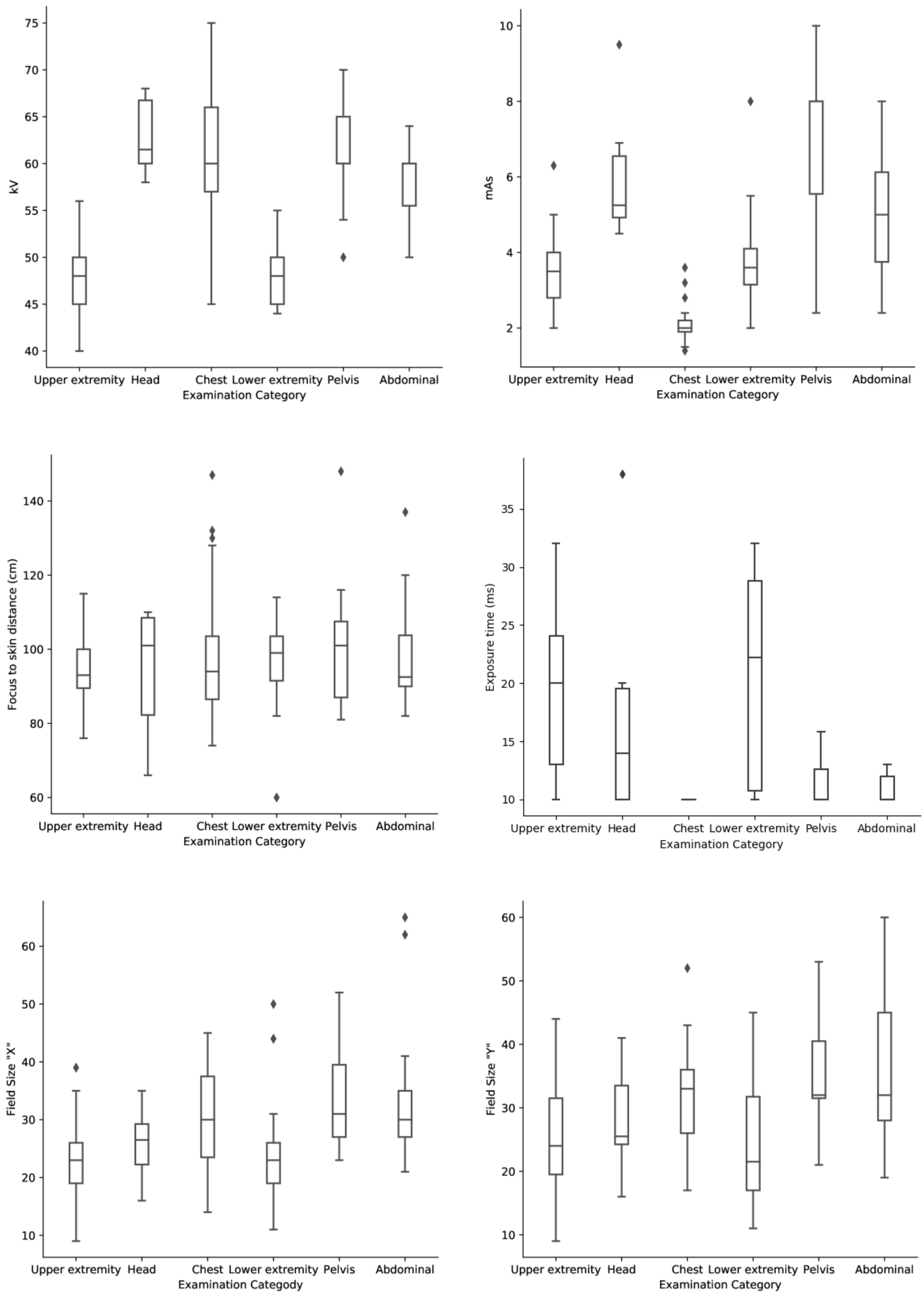

Figure 5. The Box plot for machine-specific parameters related to examination category: a) kilovoltage, b) mAs, c) focus to skin distance (cm), d) exposure time (ms), e) field size “x” (cm) and f) field size “x” (cm)

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