# Radiation Dose and Image Quality Evaluation in Paediatric Radiography

**A.P. Ladia, S.G. Skiadopoulos, C.P. Kalogeropoulou, P.E. Zampakis, G.G. Dimitriou ,G.S. Panayiotakis**

***Abstract*—Chest and abdomen radiographs are the most common examinations in paediatric radiology. It is important to ensure that patient radiation dose is kept to low level without image quality degradation. In this work, the effective dose, risk and image quality were assessed in chest and abdomen radiography. Eighty children (40 boys, 40 girls) participated in the study and they were categorized in four age groups, according to their anatomical characteristics. The dose and risk were estimated utilizing the PCXMC 2.0 code. The image quality was assessed by two radiologists based on image features provided by the CEC guidelines. The mean effective dose value was 13 μSv and 34.6 μSv for chest and abdomen, respectively. The risk was slightly higher in the case of 1 y age group. Image quality values were similar for all age groups, with a slight increase in chest radiographs compared to abdomen radiographs. Improved image quality values were obtained for the processed images, for both chest and abdomen radiographs.**

***Index Terms*— Abdomen Radiography, Chest Radiography, Radiation Dose, Image Quality**

## I. INTRODUCTION

Chest and abdomen radiographs are the most common examinations in paediatric radiology. The main advantages of chest and abdomen radiographs are the low cost and the high speed of acquisition and diagnosis. However, it is important to ensure that patient radiation dose is kept to low level, due to the increased children radiosensitivity and longer life expectancy [1] without degradation of the image quality (IQ).

Many studies have been reported dealing with patient dose, image quality or both, in paediatric radiography [2-6]. These studies refer either to film based systems, or computed radiography (CR) systems and highlight the fact that the effective dose (ED) and consequently the associated risk depend on the patient size [7].

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In this study, the ED, risk and IQ for four age groups of children undertaken chest or abdomen radiographic examination, using a CR system, were evaluated, utilizing a Monte Carlo based code, the PCXMC 2.0.

## II. PATIENTS AND METHODS

### A. *Patient Data*

Eighty children (40 boys, 40 girls) who underwent chest or abdomen examinations participated in this study. The chest radiographs were posterior- anterior and the abdomen radiographs anterior- posterior projection. All examinations were performed using the GE Model MS 18S radiology unit with tube filtration 3.5 mm Al at 80 kVp, installed in the Karamandaneio Children Hospital of Patras. The children were categorized into four age groups (1, 5, 10, 15 y), according to their anatomical (weight and height) characteristics (see Table 1). Patient data (sex, age, weight, height, body mass index (BMI)) and exposure parameters (tube voltage, tube load, Focus Skin Distance (FSD)) were collected for both examinations (see Table 2 and 3).

### B. *Entrance Surface Dose*

The most widespread indicator used in dose calculation is the Entrance Surface Dose (ESD). The x-ray tube output and the exposure parameters (tube voltage, tube load) were utilized to calculate the ESD values, using the equation [8]:

$$ESD = T.O \bullet \left(\frac{100}{FSD}\right)^2 \bullet tube\ load \bullet BSF \qquad (1)$$

where T.O. is the output of the x- ray tube (in mGy/mAs) at 80 kVp at a distance of 1 m normalized, tube load is the product of the tube current (in mA) and exposure time (in seconds), FSD is the focus skin distance (in cm) and BSF is the back scatter factor. The value of BSF used was 1.3 [9]. The values resulted from equation 1 were compared with the corresponding ESD values, as estimated by the PCXMC 2.0 code, for each patient.

Table 1. Classification of children according to age, sex and examination.

| age [y] | 1 | | 5 | | 10 | | 15 | | total |
|---|---|---|---|---|---|---|---|---|---|
| | girls | boys | girls | boys | girls | boys | girls | boys | |
| chest | 5 | 5 | 4 | 6 | 4 | 6 | 5 | 5 | 40 |
| abdomen | 5 | 5 | 5 | 5 | 6 | 4 | 5 | 5 | 40 |

Table 2. Patients data and exposure parameters for chest radiographs.

| age [y] | weight [kg] | | height [cm] | | BMI [kg/m²] | FSD [cm] | tube voltage [kVp] | | tube load [mAs] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | range | mean | range | mean | mean | mean | range | mean | range | mean |
| 1 | 8.0-10.5 | 9.40 | 72-85 | 78.7 | 15.19 | 124 | 79-82 | 79.9 | 1.62-2.3 | 1.94 |
| 5 | 17.0-19.0 | 17.70 | 104-110 | 106.6 | 15.60 | 151 | 79-82 | 80.0 | 3.22-4.3 | 3.72 |
| 10 | 27.0-33.0 | 31.50 | 131-143 | 131.0 | 16.12 | 151 | 79-83 | 80.6 | 5.01-6.0 | 5.46 |
| 15 | 49.0-59.0 | 49.00 | 158-174 | 158.0 | 19.26 | 160 | 80-90 | 83.8 | 6.09-6.9 | 6.45 |

Table 3. Patients data and exposure parameters for abdomen radiographs.

| age [y ] | weight [kg] | | height [cm] | | BMI [kg/m²] | FSD [cm] | tube voltage [kVp] | | tube load [mAs] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | range | mean | range | mean | mean | mean | range | mean | range | mean |
| 1 | 8.3-10.5 | 9.43 | 71-80 | 77.0 | 15.89 | 109 | 72-82 | 78.20 | 3.22-4.3 | 3.70 |
| 5 | 18.0-20.0 | 18.80 | 104-110 | 106.9 | 16.45 | 150 | 78-83 | 80.20 | 4.74-5.4 | 5.06 |
| 10 | 28.0-35.0 | 31.80 | 131-144 | 138.3 | 16.60 | 151 | 78-82 | 79.90 | 5.66-6.6 | 6.15 |
| 15 | 50.0-60.0 | 54.90 | 161-175 | 167.9 | 19.45 | 158 | 82-90 | 84.90 | 6.63-7.7 | 7.17 |

### C. *Dose and Risk Assessment*

One common method for evaluating radiation dose is based on calculations using Monte Carlo techniques. The Monte Carlo based software PCXMC 2.0, developed at the Medical Radiation Laboratory of the Finnish Radiation and Nuclear Safety Authority, is a code for calculating patient doses in diagnostic radiology [10]. This code was used to calculate the dose of each organ separately, as well as the ED according to the equation [10-11]:

$$E = \Sigma_T W_T \left[\frac{H_T^M + H_T^F}{2}\right] \quad (2)$$

where $W_T$ is the tissue weighting factor and $H_T^M$ , $H_T^F$ the equivalent doses for tissue T of male and female.

The ED value was used to estimate the risk for each patient undertaken chest or abdomen examination. For the assessment of risk resulting from an exposure to ionizing radiation [Risk of Exposure Induced cancer Death (REID)], the BEIRVII mathematical model was used [12].

The calculations were carried out using the Intel ® Core™ 2 Duo processor of 2.66 GHz CPU powered by Asus and 4 GB installed memory (RAM). The calculation time required for each patient was 45 to 60 min. Statistical analysis was performed to investigate the correlation between patient dose and exposure parameters. Specifically, student t-test with threshold of statistical significance of 0.05 was used.

### D. *Image Quality Evaluation*

To assess image quality and consequently the amount of diagnostic information received, a visual grading analysis of the radiographs was performed in accordance with the CEC guidelines, which define the acceptability of radiographs [13]. The visibility of the image features was assessed using a five-grade scale (see Table 4), enabling quantitative evaluation of the image quality criteria. Two radiologists, experienced in reading radiographs, interpreted the images in a random order, independently and blinded to the technique

Table 4. Grading scale for image quality criteria.

| Grade | Definition |
|---|---|
| 1. | Criterion definitely not fulfilled |
| 2. | Criterion probably not fulfilled |
| 3. | Not sure whether criterion fulfilled or not (50-50) |
| 4. | Criterion probably fulfilled |
| 5. | Criterion definitely fulfilled |

used. In total, 80 radiographs were evaluated. During reading the room illumination was dimmed and kept constant, while reading time and radiologist to monitor distance were not restricted. The image quality assessment criteria (see Tables 5 and 6) used were based on the CEC guidelines [14]. The maximum possible total image quality score for each image was 65 for chest radiographs and 25 for abdomen radiographs, if all criteria were applicable. The final total score for each image was acquired by summing the mean scores of the two observers for each image feature. The whole procedure was repeated for all images after processing of the images using the ImageJ tool [15].

Table 5. Image quality criteria for chest radiography.

| Assessment of Image Quality for chest radiographs |
|---|
| 1. Performed at peak of inspiration, except for foreign body aspiration |
| 2. Reproduction of the thorax without rotation |
| 3. Reproduction of the thorax without tilting |
| 4. Reproduction of the chest must extend from just above the apices of the lungs to T12/L1 |
| 5. Reproduction of the vascular pattern in central 2/3 of the lungs |
| 6. Reproduction of the trachea |
| 7. Reproduction of the proximal bronchi |
| 8. Visually sharp of the diaphragm reproduction |
| 9. Visually sharp of costo-phrenic angles |
| 10. Reproduction of the spine |
| 11. Reproduction of par spinal structures and visualization |
| 12. Reproduction of the retro cardiac lung |
| 13. Reproduction of the mediastinum |

Table 6. Image quality criteria for abdomen radiography.

| Assessment of Image Quality for abdomen radiographs |
|---|
| 1. Reproduction of the abdomen, from the diaphragm to the inchial tuberosities including the lateral abdominal walls |
| 2. Reproduction of the properitoneal fat lines consistent with ages |
| 3. Visualization of the kidney outlines consistent with age and depending on bowel content |
| 4. Visualization of the psoas outlines consistent with age and depending on bowel content |
| 5. Visually sharp reproduction of the bones |

### *E. Statistical Analysis*

Reliability analysis [16] was utilized in order to assess the agreement between the IQ scores of the two radiologists (inter-observer agreement) in 80 chest and abdomen radiographs. Furthermore, to assess the agreement between the IQ scores of the same radiologist (intra-observer agreement), 30 chest and abdomen radiographs were analysed. Intraclass correlation coefficient [ICC] and its corresponding 95% confidence interval [CI] were calculated for initial and processed chest and abdomen radiographs. The degree of agreement was scaled as almost perfect (ICC = [0.81-1.00]), substantial (ICC = [0.61-0.81)), moderate (ICC = [0.41-0.61]), or weak (ICC = [0.21-0.41]) [16]. Statistical analysis was performed using the IBM SPSS Statistics software package (SPSS Release 22.0, SPSS Inc., and Chicago, IL, USA).

Inter-observer agreement of radiologists was substantial for initial radiographs (ICC=0.706, CI= [0.577-0.801]) and moderate for processed radiographs (ICC=0.573, CI= [0.406-0.703]). Intra-observer agreement of radiologists was perfect for both radiologists, for both initial radiographs (ICC=0.948, CI= [0.878-0.978]; ICC=0.940, CI= [0.863-0.975], respectively) and processed radiographs (ICC=0.935, CI= [0.849-0.972]) and (ICC=0.881, CI= [0.731-0.949], respectively).

## III. RESULTS

Table 7 presents the mean ESD in chest examinations for all age groups, as calculated using the equation 1 and the PCXMC 2.0 code, together with corresponding values published in other studies [17-20], as well as with the Diagnostic Reference Levels (DRLs) reported by National Radiological Protection Board [21]. Table 8 presents the corresponding ESD values of our results and published values

Table 7. Comparison of mean ESD values with other studies and NRPB DRLs for chest examinations.

| Age [y] | ESD (μGy) for chest<br>This study (eq.1) | This study (PCXMC2.0) | Morales et al | Kiljunen et al | Compagnone et al | Nahangi et al | NRPB DRLs |
|---|---|---|---|---|---|---|---|
| 1 | 76 | 78 | 86- 87 | 40 | - | 81 | 80 |
| 5 | 89 | 86 | 90- 88 | 60 | 29 | 122 | 110 |
| 10 | 94 | 95 | 78- 78 | 110 | - | 170 | 70 |
| 15 | 107 | 109 | - | 180 | - | 213 | 110 |

Table 8. Comparison of mean ESD values with other studies and NRPB DRLs for abdomen examinations.

| Age [y] | ESD (μGy) for abdomen<br>This study (eq.1) | This study (PCXMC 2.0) | Morales et al | Kiljunen et al | Compagnone et al | Nahangi et al | NRPB DRLs |
|---|---|---|---|---|---|---|---|
| 1 | 195 | 201 | - | 220 | - | 587 | 340 |
| 5 | 290 | 312 | - | 280 | 413 | 1088 | 590 |
| 10 | 470 | 511 | - | 660 | - | 1475 | 860 |
| 15 | 955 | 960 | - | 630 | - | 2202 | 2010 |

for abdomen examinations. It worths to notice that the ESD values derived by equation 1 and PCXMC 2.0 code were practically the same. For chest radiographs, the ESD values in our study for 1 and 15 y were slightly lower than DRLs and value of other studies, except to the values reported by Kiljunen et al. The ESD values for the 5 y group in our study were higher than the values reported by Kiljunen et al. and Compagnone et al., but lower than the DRLs and the value of other studies. The ESD values for the 10 y group in our study were higher than the DRL values and the values reported by Morales et al., but comparative to the values reported by Kiljunen et al. and lower than the value reported by Nahangi et al. For abdomen radiographs, the ESD values, of our study were lower than the DRL values, as well as the values reported by other studies except the values reported by Kiljunen et al.

Table 9 presents the mean ED and REID values for all patient groups for chest and abdomen radiography. The mean value of ED for all paediatric patients studied was 13 μSv and 34.6 μSv for chest and abdomen, respectively. The mean value for ED was up to three times higher for abdomen compared to chest radiography. As expected, the minimum ED value was estimated in the case of 1 y age group, 11.9 μSv and 32 μSv for chest and abdomen radiography, respectively. For the same age group the highest REID value was estimated 0.721 • $10^{-5}$ and 1.321 • $10^{-5}$ for chest and abdomen, respectively. This occurred due to the higher radiosensitivity of tissue and the longer life expectancy of the certain group. In general, the REID values were almost double for abdomen compared to chest examination for all paediatric patient groups.

Table 10 presents the IQ score for chest and abdomen radiographs before and after image processing. The IQ score obtained was slightly higher for the chest radiographs (4.1- 4.5) compared to the abdomen radiographs (4.1- 4.2), while for the processed radiographs were 4.3- 4.6 for chest and 4.2- 4.3 for abdomen radiographs. That increase was statistically significant for both examinations.

Table 9. Mean ED values and REID values for chest and abdomen examinations.

| age | Effective dose (μSv) | | REID • $10^{-5}$ | |
|---|---|---|---|---|
| [y] | chest | abdomen | chest | abdomen |
| 1 | 11.9 | 32.0 | 0.721 | 1.321 |
| 5 | 12.9 | 34.0 | 0.695 | 1.172 |
| 10 | 13.5 | 35.7 | 0.638 | 1.107 |
| 15 | 13.8 | 36.5 | 0.601 | 1.092 |
| total value | 13.0 | 34.6 | 0.664 | 1.173 |

Table 10. Mean IQ values for all patient groups for chest and abdomen radiographs.

| age | IQ initial | | IQ processed | |
|---|---|---|---|---|
| [y] | chest | abdomen | chest | abdomen |
| 1 | 4.5±0.3 | 4.1±0.2 | 4.6±0.2 | 4.3±0.1 |
| 5 | 4.2±0.3 | 4.1±0.1 | 4.4±0.2 | 4.2±0.1 |
| 10 | 4.1±0.3 | 4.1±0.2 | 4.3±0.2 | 4.3±0.1 |
| 15 | 4.2±0.3 | 4.2±0.2 | 4.4±0.3 | 4.3±0.1 |
| total value | 4.3±0.3 | 4.1±0.2 | 4.4±0.2 | 4.3±0.1 |

Table 11. Comparison of ED values (mean and range) with other studies, for chest radiography.

| age | effective dose (μSv) for chest | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | This study | | Shatskiy et al | | Kiljunen et al | | Compagnone et al | | Nahangi et al | |
| [y] | mean | range | mean | range | mean | range | mean | range | mean | range |
| 1 | 11.9 | 11-13 | 40 | 10-130 | 7 | 3- 11 | - | | 8 | - |
| 5 | 12.9 | 12-13 | 30 | 10-140 | 11 | 2- 27 | 5 | 1- 8 | 12 | - |
| 10 | 13.5 | 13-14 | 30 | 10- 80 | 18 | 2-121 | - | | 17 | - |
| 15 | 13.8 | 13-14 | 30 | 10- 80 | 30 | 6- 73 | - | | 19 | - |

Table 12. Comparison of ED values (mean and range) with other studies, for abdomen radiography.

| age | effective dose (μSv) for abdomen | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | This study | | Shatskiy et al | | Kiljunen et al | | Compagnone et al | | Nahangi et al | |
| [y] | mean | range | mean | range | mean | range | mean | range | mean | range |
| 1 | 32.0 | 31-33 | 120 | 20-440 | 56 | 6-263 | - | | 94 | - |
| 5 | 34.0 | 33-35 | 140 | 30-440 | 72 | 8-281 | 102 | 68-134 | 193 | - |
| 10 | 35.7 | 35-36 | 340 | 140-680 | 144 | 8-267 | - | | 255 | - |
| 15 | 36.5 | 36-37 | 550 | 220-1800 | 170 | 100-283 | - | | 334 | - |

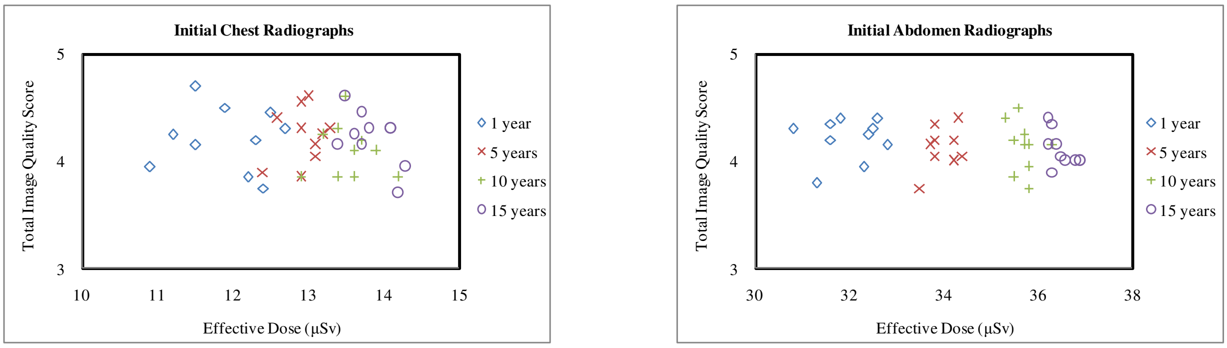


Figure 1. Total image quality score vs effective dose for the initial chest and abdomen radiographs.

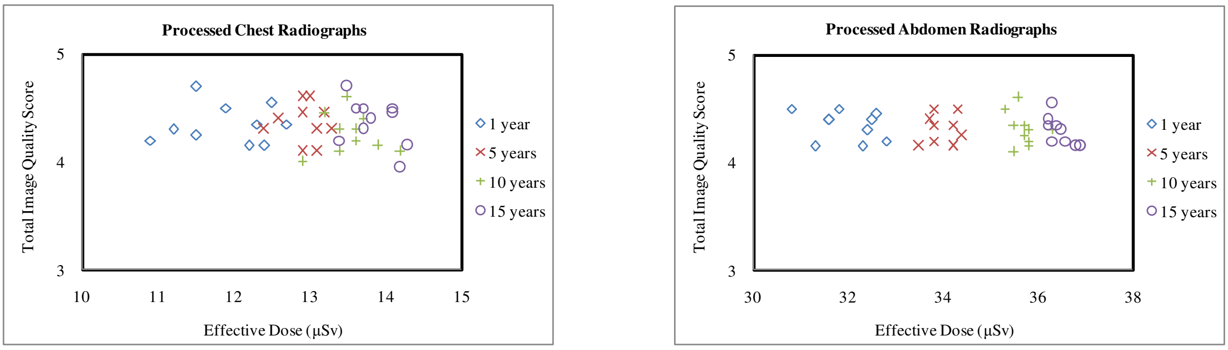


Figure 2. Total image quality score vs effective dose for the processed chest and abdomen radiographs.

## IV. DISCUSSION

The ED values (mean and range) estimated in our study were compared with the corresponding values reported in similar representative studies [17-18, 20, 22], as shown in Table 11 for the case of chest radiographs and in Table 12 for the case of abdomen radiographs. In general, the ED values for all age groups in our study were comparative or lower than those previously reported, for both chest and abdomen examinations. For chest radiography our results were comparative to the values reported by Nahangi et al. and Kiljunen et al. for the group of age 1 and 5 y. For abdomen radiography our results were comparative to the values reported by Kiljunen et al. for the groups of age 1 and 5 y, whilst our results were lower or significant lower compared to the other values reported. Regarding image quality, the IQ score obtained was high in all cases. The IQ values were slightly higher for chest radiographs compared to abdomen radiographs. Even higher IQ values were obtained for the processed radiographs. Similar remarks are obtained from Figures 1 and 2, where the total IQ scores versus the mean ED values for initial and processed chest and abdomen radiographs are presented.

The main limitations of our study are the small number of patients for each age group and the fact that examinations were performed using only one radiographic unit.

## V. CONCLUSIONS

The ED value was slightly increased with the age of the paediatric patients. The risk was slightly higher in the case of 1 y age group. The IQ values were similar for all age groups, with a slight increase in chest radiographs compared to abdomen radiographs. Improved IQ values were obtained for the processed images, for both chest and abdomen radiographs.

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