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MONTE CARLO ESTIMATION FOR PEDIATRIC BARIUM MEAL PROCEDURES

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ABSTRACT

Fluoroscopic barium meal (BM) series involve an X-ray examination of the esophagus, stomach, and duodenum, by the use of a contrast media – the barium sulfate (BaSO4). They are widely used to observe digestive functions or to diagnose abnormalities such as ulcers; tumors; inflammation of the esophagus, stomach, and duodenum; malrotations; vascular rings; and gastroesophageal reflux disease (a common ailment in children). However, this procedure uses long fluoroscopy times and multiple radiographies, resulting in high effective doses to pediatric patients, whose radiosensitivity and life expectancy are higher than in adults. Based on those data, the aims of the current study are to: determine the $P_{K,A}$ (kerma-area product) values, on the patient chest area, and the effective doses to 5 and 10 years old children. Thirty-seven different pediatric patients were studied and stratified into two group sizes: 5 and 10 years old. For each procedure, the following data was recorded: sex, age and upper chest thickness, from the patients; technical parameters of the procedure (kV, fluoroscopy time and number of radiographies); distances (focus-detector and focus-table) and field size on the examination table. Three pairs of LiF:Mg,Ti thermoluminescent dosimeters were positioned at the center of the child´s sternum. After that, upper chest thickness was subtracted from focus-table distance, so focus-patient distance was obtained. Using the field size on the table and applying similar triangles concepts, the field size on the patient was measured, which was multiplied by the mean kerma (from the dosimeters), so that $P_{K,A}$ could be determined. To estimate the effective dose, $P_{K,A}$ and technical parameters of the procedure (kV, total filtration, focus-detector distance and field size on the patient) were written in a Monte Carlo software simulation. The results of $P_{K,A}$ and effective doses were higher than studies used for comparison, which shows the importance of an optimization implementation.

1. INTRODUCTION

Fluoroscopic barium meal (BM) studies involve an Xray examination of the esophagus, stomach, and first part of the small intestine (duodenum). They are widely used to observe digestive functions or to diagnose abnormalities such as ulcers; tumors; inflammation of the esophagus, stomach, and duodenum; and gastroesophageal reflux disease (a common ailment in children). In these procedures, to show the anatomy in radiographic images, the upper gastrointestinal (UGI) tract is filled with barium sulfate (BaSO4), a contrast material [1].

The fact that children have higher life expectancy and radiosensitivity than adults are concerning issues. In adult individuals, only tissues subject to high levels of cell turnover are exposed to greater radiation risk. This risk is even higher in infancy and early childhood and in adolescence it, gradually, approaches the risk to which adults are exposed [2].

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As malignant lesions, radiation-induced, remain latent for years, children and adolescents are prone to experience them. If it´s considered that the probability of requiring X-ray diagnostics is higher before the age of 1 year and falls until the school age, the differences between adult and pediatric X-ray diagnostics become even clearer. As a result, the individual and collective radiation risk is particularly high for infants and small children [2].

In a fluoroscopic procedure, there is a large exposure to X-radiation by the patient – this occurs due to the long fluoroscopy time or multiple radiographs – which results in high doses to the patients. Effective doses are important information to estimate the risk, due to exposure, of stochastic effects development. However, this quantity is not directly measured. Therefore, Monte Carlo simulation is used to calculate the conversion factor from a dosimetric quantity (kerma-area product – $P_{K,A}$ – for example) [3]. The use of mathematical phantoms in Monte Carlo simulation is widely used for calculating effective doses in some researches [4-6].

In the study performed by Iacob *et al*, effective doses in pediatric children, who subjected to BM procedures, were verified. First, it was determined the $P_{K,A}$ values in the patients, during the procedures. After that, these values were used to estimate effective dose in a Monte Carlo simulation, through the use of two mathematics phantoms – representing 5 and 10 years old, whose results are, respectively, 0.9 ± 0.3 mSv and 1.3 ± 0.6 mSv [4].

Emigh *et al* conducted a study to determine the value of $P_{K,A}$ and the effective dose in anthropomorphic phantoms, equivalent to 5 and 10 years old children, when de BM procedure was simulated. Irradiations occurred at the General Electric "PrecisionTM 500D" fluoroscope, whose total filtration is 3.0 mmAl + 0.2 mmCu and a Diamentor (a parallel-plate ionization chamber) was used for the measurement of $P_{K,A}$. First, the phantoms were exposed to a mean fluoroscopy time of 3.6 min, when an average of four radiographs were taken, and the $P_{K,A}$ was determined. After that, a Monte Carlo simulation was performed to verify the effective dose. The results are 0.77 mSv and 0.75 mSv for, respectively, 5 and 10 years old anthropomorphic phantoms [5].

Sulieman *et al* found the mean values of entrance skin dose (ESD) and effective dose for 5 years old children who underwent BM procedures, held at the undercouch system Siemens “SIREMOBIL Compact L” fluoroscope with total filtration of 2.5 mmAl. ESD was obtained through the use of three LiF:Mg,Cu,P thermoluminescent dosimeters (TLDs) positioned in the center of the radiation field. The patients were exposed to a mean fluoroscopy time of 4.2 min, when an average of six radiographs were taken. The mean value of ESD, was used to estimate the equivalent doses in organs and tissues in the software provided by the "National Radiological Protection Board". From the equivalent doses, there was obtained the effective dose, whose the mean result is 0.3 mSv [6].

Based on those data, the aim of the current study is to determine the effective doses to 5 and 10 years old children through $P_{K,A}$ values obtained on the patient chest area.

2. METHODOLOGY

This study was performed at “Pequeno Príncipe Hospital”, one of the largest pediatric hospitals in Brazil. The procedures were carried out in the overcouch fluoroscopy system

Philips "Diagnost 93", with total filtration of 2.5 mm Al. Thirty-seven different pediatric patients were studied and stratified into two group sizes: 5 and 10 years old. For each procedure, the following data was recorded: sex, age and upper chest thickness, from the patients; technical parameters of the procedure (kV, fluoroscopy time and number of radiographies); distances (focus-detector and focus-table) and field size on the examination table. The ethics and research committee approved the study and an informed consent was obtained from the children's parent or legal responsible prior to the procedure.

TLDs LiF:Mg,Ti (MTS), circular chips with 4.5 mm diameter and 0.9 mm thickness, from "radPRo International gmBH" (Wermelskirchen, Germany) were used to estimate $P_{K,A}$. The TLD readings were done through the following heating procedure: 160^{o} C for 10 seconds, 300^{o} C for 20 seconds and 400^{o} C for 10 seconds. After the reading, the dosimeters were annealed in an oven at 400^{o} C for 60 min, in order to restore the material to its original energy state [6].

The dosimeters were encapsulated in pairs in numerically identified plastic envelopes (as is recommended in literature [7]), whose material is the same of intraoral film package, used in dental radiology. This kind of material allows the dosimeter to be sheltered from light and can be used on the patient in the region of the primary beam without causing any image distortion.

The TLDs were calibrated in the fluoroscopy equipment, when the procedures were performed, so that the X-ray beam quality was equivalent to that of the beam used in the procedure. The nominal radiography voltage was fixed at 60 kV (the mean voltage applied in pediatric barium meal procedures) and the mAs values varied from 25 to 45. After the exposure, a linear function (as well as its equation) between the air-kerma (μgy) and the TLD reading was obtained.

Three pairs of properly packaged MTS TLDs were positioned at the center of the sternum (upper-chest region), as shown in Figure 1. To determine $P_{K,A}$, the focus-table distance ("A"), the thickness of upper-chest region ("B"), and field area on the examination table were measured. "B" was subtracted from "A", so that the focus-patient distance ("C") could be determined. Then, using the field area on the table and "C" and applying mathematical concepts of similar triangles, the field area on the surface of the patient was calculated. Figure 2 explains this calculation process. The field area on the patient was, then, multiplied by the mean entrance-surface air kerma, obtained by the TLDs arranged on the patient [8].

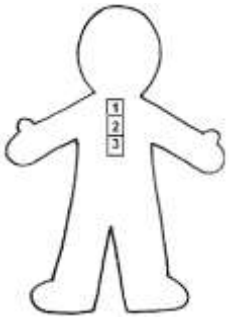

Figure 1. Child figure model with identified TLDs positioned in the upper-chest center.

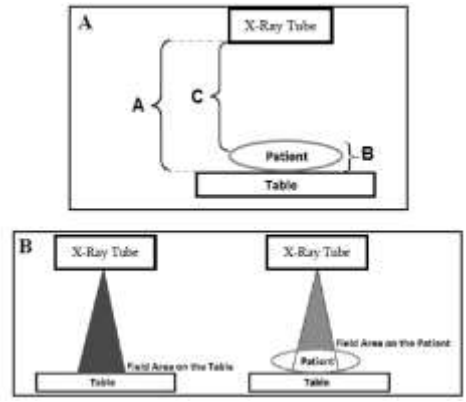

Figure 2 – (A) "A", "B" and "C" measured for each patient in this study; (B) left and right triangles used to determine the field area on the patient [8].

In order to obtain the effective dose, the software "CalDose", developed by the Computational Dosimetry Group of the Federal University of Pernambuco (Recife, Brazil), was employed. This software uses mathematical human phantoms (adult and pediatric) to calculate equivalent doses in organs and tissues and effective doses, using Monte Carlo code. In the case of pediatric BM examinations it is possible to choose, only, mathematical phantoms representing 5 and 10 years old children.

After setting the phantom age, some technical parameters (such as: kV, total filtration, focus-detector distance, field size and the measured $P_{K,A}$) were inserted in the software. Then, the simulation resulted in a table containing equivalent doses, in many organs and tissues, and the effective dose. The showed doses are superior to 0.0005 mSv and provided statistical errors less than 10% and.

3. RESULTS AND DISCUSSION

The Figure 3 shows the linear graph Dose x TLD reading, and its equation – which has a coefficient (1.569) that must be multiplied for the future TLD reading, so that the absorbed dose by the dosimeter is determined. The equation error is 0.044.

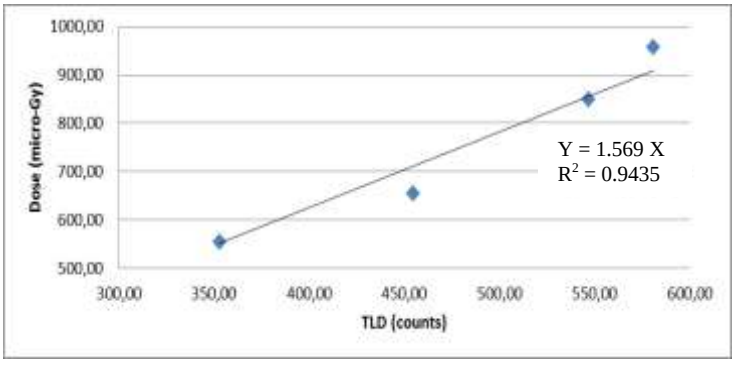

Figure 3. Dose ("Y") x TLD reading ("X") graph showing the linear equation.

Table 1 shows the $P_{K,A}$ values and the effective doses, for 5 and 10 years old patients, obtained at this study and the comparison with the mentioned studies.

Table 1. Mean Fluoroscopy time (FT) and number of radiographies (NR), $P_{K,A}$ and effective doses for 5 and 10 year old children and the comparison with mentioned studies.

	FT (min) / NR		$P_{K,A}$ (cGy.cm^2)		Effective Dose (mSv)	
	Age (years)		Age (years)		Age (years)	
	5	10	5	10	5	10
Current Study	1.3 / 7	1.3 / 6.5	177 ± 5	329 ± 6	1.1 ± 0.1	1.5 ± 0.3
Iacob [4]	------		125 ± 43	270 ± 103	0.9 ± 0.3	1.3 ± 0.6
Emigh [5]	3.6 / 4		18.2	82.5	0.77	0.75
Sulieman [6]	4.2 / 6	------	------	------	0.30	------

Despite the fluoroscopy time results, at this study, are much lower than other ones and the number of taken radiographies, verified at this study, are close to other researches, it appears that the dose values ($P_{K,A}$ and effective dose) are much higher than the comparative results. Some reasons for this may be:

- The high field size during procedures (there was no collimation during examinations);
- The little total filtration (Emigh *et al* performed their study in a fluoroscope whose total filtration was 3.0 mmAl + 0.2 mmCu);
- No pattern has been established for the examination techniques, and there are four different operators who handle the equipment [8] and each one performs the examination in a different way.

Based on the obtained results, it must be implemented optimization techniques, so that lower field sizes and, consequently, values of $P_{K,A}$ and effective doses can be achieved.

4. CONCLUSIONS

The aims of the current study were to determine the $P_{K,A}$ values, on the patient chest area, and the effective doses to 5 and 10 years old children submitted to BM procedures. It was verified that the results are higher than mentioned studies, despite of low fluoroscopy time and the number of taken radiographies. Some reasons may be the high field size during procedures, since there is no collimation, the little total filtration and the pattern lack in performing the procedures. Therefore, it must be implemented optimization techniques, so that lower field sizes and, consequently, values of $P_{K,A}$ and effective doses can be achieved.

5. REFERENCES

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