Dosimetric evaluation of X-ray examinations of paranasal sinuses in pediatric patients*

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INTRODUCTION

In radiological examinations of the face, radiosensitive anatomical structures, such as the eyes and thyroid, are exposed to ionizing radiation, representing a risk to the patient, due to the possibility of producing biological effects induced by the interaction of the radiation with the tissue. Special attention should be given to radiological examinations performed in pediatric patients, because, in comparison with...
those of adults, their cells are more radiosensitive and have a longer life expectancy, which increases the risk of stochastic effects\textsuperscript{1}).

Clinical requests for X-ray examinations of the sinuses are quite common in children\textsuperscript{2,3}, in order to investigate diseases of the upper respiratory tract, such as hypertrophy of the adenoids, inflammatory diseases of the sinus cavities, sinus infections, tumors, and facial fractures\textsuperscript{4,5}. Conventional radiography for the radiological study of the sinuses can be performed as follows\textsuperscript{6,7}: lateral X-rays (cavum radiographs); posteroanterior occipitomental X-rays (Waters view); and posteroanterior occipitofrontal X-rays (Caldwell view).

The objective of this study was to evaluate the entrance surface air kerma ($K_{a,e}$) for pediatric patients undergoing radiological examinations of the sinuses at two hospitals in Recife, PE, Brazil. We also estimated the air kerma values in the thyroid region and around the eyes.

**MATERIALS AND METHODS**

The study was conducted at two public hospitals (hereafter referred to as hospital A and hospital B), both of which specialized in the care of pediatric patients. Hospital A has approximately 112 beds, distributed among various clinical areas. Hospital B is a referral center for maternal and child health, with 714 beds and more than 600,000 annual visits to its various clinics. Both hospitals are philanthropic and provide services via the Brazilian Unified Health Care System. Hospital B has two rooms for performing X-ray examinations, both equipped with Philips Bucky Diagnost X-ray equipment, whereas hospital A has only one X-ray examination room, which is equipped with a Shimadzu R 20 X-ray system. None of the X-ray machines evaluated are equipped with automatic exposure control, and the image acquisition system is based on radiographic films at both institutions.

We created a form designed to collect data related to anthropometric characteristics of the patient (gender, weight and height), the type of examination/projection, and the irradiation parameters employed (kV, mAs, focus-to-skin distance, focus-to-film distance, and exposure time). Data were collected by the authors of the study, and neither institution maintains nested records of such information. We monitored the radiological examinations of patients ≤ 15 years of age. For data analysis, patients were divided into the following age groups: 0–1 year; 1–5 years; 5–10 years; and 10–15 years.

**Determination of the $K_{a,e}$**

The $K_{a,e}$ was determined on the basis of the yield of the X-ray tube and the irradiation parameters (indirect method). For that purpose, we used a Radcal ionization chamber, model 20X6-6, positioned in the center of the radiation field, 100 cm from the focal spot and 30 cm from the surface of the table. We measured the air kerma for different values of tube voltage (kV), using a fixed value for the current-time product (mAs). For each kV value, we made three measurements. The mean value obtained was corrected for the pressure-temperature factor and for the calibration factor of the ionization chamber. The calibrations were performed at the Laboratório de Metrologia das Radiações Ionizantes, Departamento de Energia Nuclear da Universidade Federal de Pernambuco (LMRI/DEN-UFPE, Ionizing Radiation Metrology Laboratory, Department of Nuclear Energy at the Federal University of Pernambuco), which follows the standards set by the National Laboratory for the Metrology of Ionizing Radiation at the Radioprotection and Dosimetry Institute of the Brazilian National Nuclear Energy Commission.

The yield of X-ray equipment corresponds to the air kerma value (in mGy) per mAs, at a distance of 1 m from the focal spot. A curve for the yields of the different voltage values was constructed and used for determining the yield under the irradiation conditions employed in each of the examinations evaluated. For each patient, the $K_{a,e}$ was determined by the following equation\textsuperscript{8}:

$$K_{a,e} = R_iQ(D_{ref}/DFP)\cdot BSF$$

where $R_i$ is the yield of the X-ray tube for radiographic technique employed in the examination, interpolated from the yield curve in function of the voltage, of the $R_i = a.(kV)^b$ type, $a$ and $b$ being curve fitting parameters; $Q$ is the product of tube current by exposure time (mAs) used in the examination; $D_{ref}$ is a distance of 1 m for which the yield has been adjusted; DFP is the distance between the focal point and the skin of the patient; and BSF is the backscatter factor, which is a function of the size of the field, the filtration of the equipment and the radiographic technique used in the examination. A fixed BSF value of 1.30 was adopted\textsuperscript{9}.

**Estimation of doses near radiosensitive organs using thermoluminescent dosimeters**

Pairs of LiF:Mg,Ti (TLD-100) thermoluminescent dosimeters were encapsulated in thin plastic casings (one pair per casing) and placed on the skin of the patient around the eyes and thyroid. The dosimeter pair taken to each institution was always accompanied by another pair of dosimeters that were not irradiated. The reading from those dosimeters (in a white casing) was subtracted from the reading from the irradiated dosimeters. The mean reading of the two dosimeters contained in each casing was converted into air kerma using the calibration curve obtained with diagnostic quality X-ray beams at the LMRI/DEN-UFPE\textsuperscript{10}.

**RESULTS**

**Characteristics of the radiological examinations**

Figures 1A and 1B show the age distribution of the patients who underwent radiological examinations with lateral and posteroanterior (occipitofrontal and occipitomental) X-rays, respectively. We evaluated 159 radiographs of the sinuses, of which 103 were lateral X-rays (cavum radiographs) and 56 were posteroanterior X-rays, including occipitofrontal and occipitomental X-rays (Caldwell and Waters views, respectively).
Approximately 60% of the patients undergoing radiological examination of the sinuses at either hospital were male. At hospital A, 72.8% of the patients in whom lateral X-rays were obtained were male, compared with 62.5% of those in whom posteroanterior (occipitofrontal and occipitomental) X-rays were obtained. At hospital B, males accounted for 50.0% of the patients undergoing radiological examination of the sinuses, in either view. Therefore, the gender distribution was much more balanced among the patients seen at hospital B.

Irradiation parameters

The minimum, mean, and maximum voltage used in lateral and posteroanterior (occipitofrontal and occipitomental) X-ray examinations of the sinuses are shown in Table 1. The accuracy and reproducibility of voltage (kV) values provided by the X-ray machines employed were previously evaluated using quality protocols devised by the Brazilian National Ministry of Health\cite{11,12}. The variation in the reproducibility of the voltage value was 0.1% for the equipment at both hospitals. However, in tests of the variance between the voltage supplied to the X-ray tube and the value indicated on the panel, the equipment employed at hospital A showed a variance of 2.2%, whereas the equipment employed in the two separate X-ray examination rooms at hospital B showed variances of 2.0% and 4.0%, respectively. The minimum, mean, and maximum current-time product (mAs) of the X-ray tubes used in the radiological examinations of the sinuses (in lateral, occipitofrontal, or occipitomental X-rays) are shown in Table 2.

$K_{\text{measured from the X-ray tube yield}}$

The distribution of the estimated $K_{\text{measured from the X-ray tube yield}}$ values in radiological examinations of the sinuses of pediatric patients is shown, by age group, in box and whisker plots in Figures 2A and 2B for lateral and posteroanterior (occipitofrontal

### Table 1—Voltages used in examinations of the sinuses.

| Type of examination | Age group | Hospital A | | | Hospital B | | |
|---------------------|-----------|------------|---|---|------------|---|
|                     | Min | Mean | Max | Min | Mean | Max |
| Lateral             | 0–1 year | — | — | — | 70 | 70 | 70 |
|                     | 1–5 years | 61 | 68.82 | 72 | 70 | 71.1 | 73 |
|                     | 5–10 years | 60 | 69.44 | 74 | 66 | 71.71 | 77 |
|                     | 10–15 years | 69 | 74.08 | 91 | 70 | 71.8 | 73 |
| Occipitofrontal     | 0–1 year | — | — | — | — | — | — |
|                     | 1–5 years | 55 | 58.33 | 60 | 70 | 75.33 | 81 |
|                     | 5–10 years | 60 | 60.33 | 62 | 70 | 73.5 | 77 |
|                     | 10–15 years | 60 | 60.57 | 63 | — | — | — |
| Occipitomental      | 0–1 year | — | — | — | — | — | — |
|                     | 1–5 years | 63 | 65.33 | 68 | 73 | 76.11 | 77 |
|                     | 5–10 years | 63 | 64.66 | 65 | 70 | 73.33 | 77 |
|                     | 10–15 years | 65 | 65.28 | 66 | — | — | — |

Min, minimum; Max, maximum.

### Table 2—Current-time products used in examinations of the sinuses.

| Type of examination | Age group | Hospital A | | | Hospital B | | |
|---------------------|-----------|------------|---|---|------------|---|
|                     | Min | Mean | Max | Min | Mean | Max |
| Lateral             | 0–1 year | — | — | — | 4.0 | 4.67 | 5.0 |
|                     | 1–5 years | 2.88 | 3.37 | 5.76 | 4.0 | 4.95 | 5.0 |
|                     | 5–10 years | 2.88 | 3.74 | 5.76 | 4.0 | 5.15 | 6.5 |
|                     | 10–15 years | 3.24 | 3.51 | 5.04 | 5.0 | 5.0 | 5.0 |
| Occipitofrontal     | 0–1 year | — | — | — | — | — | — |
|                     | 1–5 years | 20.16 | 20.25 | 23.72 | 5.0 | 9.65 | 12.5 |
|                     | 5–10 years | 43.2 | 45.6 | 50.4 | 5.0 | 5.0 | 5.0 |
|                     | 10–15 years | 50.4 | 50.4 | 50.4 | 20.0 | 20.0 | 20.0 |
| Occipitomental      | 0–1 year | — | — | — | — | — | — |
|                     | 1–5 years | 18.0 | 37.2 | 50.4 | 6.3 | 10.25 | 12.5 |
|                     | 5–10 years | 43.2 | 46.8 | 50.4 | 5.0 | 5.0 | 5.0 |
|                     | 10–15 years | 50.4 | 50.4 | 50.4 | 20.0 | 20.0 | 20.0 |

Min, minimum; Max, maximum.
or occipitomental) X-rays, respectively. In this distribution, the upper and lower borders of the rectangle correspond to the first and third quartiles (25% and 75% of the data, respectively). Therefore, the rectangle itself contains 50% of the data. The line inside the rectangle indicates the median and the rectangle indicates the mean. The whiskers indicate the maximum and minimum value of the data. Values outside the distribution (outliers) are indicated by asterisks. Posteroanterior X-rays of the sinuses are taken from two views—occipitofrontal and occipitomental—and the values shown correspond to the sum of the $K_{ae}$ for the two views in each patient. For better visualization, the distributions of the $K_{ae}$ values estimated for the lateral and posteroanterior X-rays of the sinuses obtained at hospital B are shown in Figures 3A and 3B, respectively.

Doses near radiosensitive organs, as determined with thermoluminescent dosimeters

Figures 4A and 4B show the entrance and exit $K_{ae}$ values, respectively, for the area around the eyes of the patients

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**Figure 2.** Distribution of $K_{ae}$ values (in mGy) estimated for radiological examinations of the sinuses with lateral X-rays (A) and posteroanterior (occipitofrontal and occipitomental) X-rays (B), by age group, for the two hospitals participating in the study.

**Figure 3.** Distribution of $K_{ae}$ values (in mGy) estimated for radiological examinations of the sinuses in lateral (A) and posteroanterior (occipitofrontal and occipitomental) X-rays (B), by age group, for hospital B.

**Figure 4.** Distribution of $K_{ae}$ values (in mGy) estimated for the area around the eyes, in relation to the primary X-ray beam entrance (A) and exit (B), in lateral X-rays of the sinuses.
in lateral (paranasal sinus) X-rays. Figures 5A and 5B show the estimated $K_{ae}$ values for the left and right eyes, respectively, in posteroanterior (occipitofrontal and occipitomalental) X-rays. The distributions of the $K_{ae}$ values estimated for the thyroid region of pediatric patients submitted to lateral and posteroanterior (occipitofrontal and occipitomalental) X-ray examinations of the sinuses are presented in Figures 6A and 6B, respectively.

**DISCUSSION**

For the sinus examinations evaluated, the irradiation parameters shown in Tables 1 and 2 were compared with the data presented in best practice guidelines developed in England\(^{(13)}\), which established quality criteria for such procedures. According to those guidelines, the voltage used for posteroanterior X-rays obtained in the occipitomalental view should be 65 kV in patients 5–10 years of age and 78 kV for those 10–15 years of age, the use of such examinations not being recommended in patients under 5 years of age. The analysis of the results obtained in the present study showed that 25% of the posteroanterior X-rays obtained in the occipitomalental view in patients 5–10 years of age, at both hospitals, were carried out at voltages higher than that recommended in the guidelines cited.

For lateral X-rays of the sinuses, the best practice guidelines advise the use of 62 kV for patients 1–5 years of age, 65 kV for those 5–10 years of age, and 70 kV for those 10–15 years of age. The results of the present study show that the voltages employed were higher than the recommended values in over 80% of the examinations carried out at the two hospitals evaluated. That is attributable to the use of an antiscatter grid, which is not recommended for this age group, because there is no significant radiation scattering in such small patients. The use of an antiscatter grid requires the use of higher tube voltages to increase the penetrating power of the X-ray beam in order to achieve the same image quality.

Analyzing the $K_{ae}$ values estimated for lateral X-rays (Figure 2A), we observed that nearly all of the radiological examinations performed at hospital B were in accordance with the recommendations of the previously cited best practice guidelines, which recommends $K_{ae}$ values of 0.11 mGy, 0.16 mGy, and 0.37 mGy for patients 1–5 years of age, 5–10 years of age, and 10–15 years of age, respectively. Only 2% of the estimated $K_{ae}$ values for examinations performed at that hospital were above the recommended value, and all of those were in patients 1–5 years of age. However, all of the $K_{ae}$ values estimated for the radiological examinations performed at hospital A were above reference values specified in the best practice guidelines, up to 8 times higher in some cases.

For radiological examinations of the sinuses involving posteroanterior (occipitofrontal and occipitomalental) X-rays
Among the radiological examinations of the sinuses performed at hospital A, the air kerma values in the thyroid region were higher during lateral X-ray examinations (Figure 6A) than during posteroanterior X-ray examinations (Figure 6B). That is attributable to the fact that the location of the thyroid puts it directly in the path of the primary X-ray beam when the head of the patient is in profile.

As for the area around the eyes, air kerma values in the thyroid region during lateral X-rays were higher at hospital A than at hospital B, with the exception of those obtained for examinations performed in patients 10–15 years of age. This again contraindicates the use of cylindrical collimators (as were used at hospital A), for the reasons set forth above.

There has been little research on the risk of thyroid cancer due to radiological examinations. Most studies of thyroid cancer risk related to radiation exposure have dealt with the accidents at Chernobyl and Fukushima or with survivors of the atomic bombings of Hiroshima and Nagasaki\(^{15–17}\).

Studies on the effects that exposure to low doses of radiation has on the thyroid have dealt with changes in its functioning, such as the onset of autoimmune diseases and cysts, especially in female patients\(^{18}\).

**CONCLUSION**

The results of the present study allow us to conclude that, at the two hospitals under study, the irradiation parameters, especially kV and mAs, are higher than those recommended in best practice guidelines. The high values of these parameters are associated with the unnecessary use of antiscatter grids, which are not recommended for examinations in patients under 10 years of age. Cylindrical collimators (for restricting the irradiation field size), the use of which is recommended for radiological examination of the sinuses, were used only by the staff at hospital A. Despite this protection, the \(K_{ce}\) values obtained for the examinations performed at that hospital were well above the value suggested in the best practice guidelines, up to eight times higher in some cases. At both hospitals, optimization strategies are called for, in order to minimize patient exposure to radiation and thus reduce the risk of deleterious effects.

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