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Evaluation of radiation dose to pediatric patients during certain special procedures

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HIGHLIGHTS

- Pediatric radiation dose has been evaluated for three of the most common fluoroscopic procedures.
- Radiation doses were measured using calibrated TLD GR200A.
- Pediatric patients of concern and ESAK doses showed large variations.
- The patient doses in this study are within the reported studies suggesting that the pediatric patients are adequately protected.

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ABSTRACT

This study was intended to measure pediatric entrance surface air kerma (ESAK) and effective dose during micturating cystourethrography (MCU), intravenous urography (IVU) and barium studies (barium meal, enema, and swallow) and to propose a local diagnostic reference level (DRL). ESAK was measured for patients using calibrated thermoluminescent dosimeters (TLDs, GR200A). Effective doses (E) were calculated using the National Radiological Protection Board (NRPB) software. A total of 236 special pediatric procedures were investigated. 21.7% of the sample comprised barium procedures, 18.6% were MCU procedures while 59.5% of the sample were IVU procedures. The mean ESAK measurements (mGy) were 2.1 ± 0.8, 3.0 ± 23 and 1.2 ± 0.2 for barium meal, enema and swallow in the same order. The mean patient dose for IVU procedures was 12.4 ± 8.7 mGy per procedure and the mean patient dose per MCU procedure was 5.8 ± 7 mGy. Local DRLs were proposed for all procedures. The patient doses in this study are within the reported values, suggesting that pediatric patients are adequately protected.

1. Introduction

Medical exposure from diagnostic examinations contributes over 95% of man-made radiation exposure and is only exceeded by natural background as a source of exposure to world's population (UNSCEAR, 2008). Mettler et al. (2009) estimated that on average, a child will undergo 7 radiological examinations by the age of 18 in the United States. Radiation exposure is a concern in both pediatric and adults in terms of cancer or hereditary effects and tissue reactions. This is particularly important when the patient is a child, because radiological examinations carry a higher risk per unit of radiation dose for the development of cancer in infants and children compared to adults. The higher risk is explained by the longer life expectancy in children for any harmful effects of radiation to manifest and the fact that developing organs and tissues are more sensitive to the effects of radiation (ICRP, 2013; Alzen and Benz-Bohm, 2011). In addition, children's tissues have higher water content than adult tissues. This means that more radiation is absorbed and dispersed, so a higher dose is needed to penetrate a layer of tissue of the same thickness (Alzen and Benz-Bohm, 2011). As a result, the radiogenic risk for developing a radiation-related cancer is 2–3 times higher for a young child compared with an adult exposed to an identical radiation dose (ICRP, 2013). Moreover, the small size of newborn infants brings all organs within or closer to the irradiated volume, resulting in a higher radiation dose per procedure than may be the case with adults (Sulieman et al., 2011a; Armpilia et al., 2002). In addition to that, the wide range of infants' weight makes standardization of the procedure more complicated. Particular

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problems that were noted in previous studies regarding pediatric imaging include poor beam collimation, inadequate devices for immobilization, lack of adequate quality control and the need for age-specific exposure factors based on appropriate anatomical parameters (ICRP, 2013; Alzen and Benz-Bohm, 2011; Sulieman et al., 2011a; Armpilia et al., 2002).

Therefore, proper justification and optimization of procedure is important to prevent patients from an unintended or unnecessary radiation dose, particularly since these procedures could lead to relatively high absorbed doses both in patients and comforters (i.e. individuals helping in the support, care and comfort of the children during the examination; ICRP, 2013).

Micturating cystourethrography (MCU), intravenous urography (IVU) and barium studies are the most frequent fluoroscopic procedures performed in children (Sulieman et al., 2007; ICRP, 2001). While attention to radiation risk for children has increased in recent years, still few studies have been performed in the field of dose calculation and the related risk during chest radiography compared to the frequency of the procedure (Mettler et al., 2009; Alzen and Benz-Bohm, 2011; Sulieman et al., 2007; Sulieman et al., 2011a, 2011b; Elhag et al., 2012; Livingstone et al., 2008; Sulieman et al., 2010; Yakoumakis et al., 2013). These studies have shown that there is a wide range of entrance surface air kerma (ESAK) values for the same pediatric X-ray examination. The ICRP recommends the establishment of diagnostic reference levels as a tool for optimizing the radiation dose delivered to patients in the course of diagnostic and/or therapeutic procedures (ICRP, 2001).

This study was intended to measure patient ESAK and effective dose during the following procedures: barium studies (barium meal, enema, and swallow), micturating cystourethrography (MCU) and intravenous urography (IVU) for pediatric patients.

2. Materials and methods

2.1. Patient population

A total of 236 special (fluoroscopic) pediatric procedures were investigated. 21.6% (51 patients) of the sample were barium procedures, 18.6% (44 patients) had undergone MCU procedures while 59.7% (141 patients) of the sample were IVU procedures. The ethics and research committee approved the study and informed consent was obtained from the comforter of the child prior to the procedure. For each procedure, mean values of patient's age (year) and weight (kg), tube potential (kVp), exposure setting (mAs) and ESAK values were recorded. Patient ESAK was measured by attaching an envelope containing 3 TLDs to patients' skin on the central axis of the X-ray beam entrance using TLD chips (GR 200A).

2.2. TLD measurements

Patients' dose measurements were made using a set of 80 thermoluminescent dosimeters (TLD-GR200A; PTW, Freiburg, Germany). Circular chips of lithium fluoride doped with Mg, Cu and P (LiF:Mg,Cu,P) and with dimensions of 0.8 mm thickness by 4.5 mm diameter were used in this study. GR200A has many characteristics that made it preferable for patient dose measurements. Effective atomic number (Z_{eff}=8.2) that makes its tissue equivalent ($Z_{eff,tissue}$=7.42), and a wide range of linearity (from 10^{-7} Gy up to 10 Gy), 35 times more sensitive than TLD-100, energy dependence (photon: 30 keV~3 MeV) less than 20% and repeatability less than 2% are the most important characteristics (Furetta et al., 1994).

Prior to measurements all TLDs were calibrated under reproducible reference conditions using a Toshiba Rotande model (T6-6TL-6) against ionization chamber PTW-CONNY II, connected to a radiation monitor controller at 100 cm source skin distance (SSD). Both the chamber and the electrometer were calibrated for the energy range 30–120 kVp at the National Standard Laboratory. TLD calibration was according to international protocols for the range of energies used in the study (Martin et al., 1998; Sulieman et al., 2007). The TLD chips were calibrated in the same energy range used during imaging procedures. For the TLD and chamber irradiation, a poly(methyl methacrylate) (PMMA) calibration test bed was constructed with the dimensions $30 \times 30 \times 5$ cm^3, which simulates patient's lateral and backscatter conditions. The first PMMA slab was used to accommodate the TLD chips in an array of slots 10×10. Each TLD was identified by its position in the array. Individual calibration factors were obtained by irradiating the entire group to the same dose. The measured signal of each TLD was divided by the mean signal of the group. This process was repeated three times to reduce the effect of statistical variations and to determine the stability and reproducibility of the signal. TLDs with sensitivity within 4% were used in this study. All the TLD chips had the same thermal history. The calibration cycle was carried out every month. TLD chips were handled with vacuum tweezers to avoid scratching the surface.

The TLD signal was read using an automatic TLD reader (Fimel PCL3, France) in an atmosphere of inert nitrogen. The PCL3 reader provides fast readings of a large number of TLD samples with a reproducibility of $0.3 \pm 0.5\%$ (1 SD). The stability of the reader was checked before any reading session. Nitrogen is supplied at a flow rate of 2 l/min to the reader in order to obtain an oxygen-free environment, hence reducing triboluminescence.

The read-out was at a 155 °C preheat temperature and the signal was acquired from 155 to 260 °C with a heating rate of 11 °C/s. Three TLDs were inserted in a plastic envelope made of transparent polyethylene plastic foil placed on the organ site and were fixed in the required position. Before each irradiation all dosimeters were annealed in an annealing oven (TLDO; PTW, Freiburg, Germany) at 240 °C for 10 min followed by rapid cooling to room temperature in order to restore the material to its original energy state. TLDs' read-out was taken directly after the irradiation to exclude any fading effect. The radiation dose received by the patient was calculated using the individual calibration factors of the chips and relating that reading to the reading of the standard TLDs, which had received a known dose. The mean background signal for unirradiated TLDs was subtracted before any calculation.

Radiation dose (D) was calculated by the following equation:

$$D = \frac{TL_m ECC}{TL_s/D_s} \quad (1)$$

where TL_m is the measured TLD signal in nanocoulomb units (nC), ECC is the element correction coefficient, and TL_s and D_s are the TLD signal and IC reading after irradiation to equal dose simultaneously (standard dose).

2.3. Radiographic equipment and imaging protocol

All the procedures were performed at three radiology departments equipped with different X-ray machines as illustrated in Table 1. Radiographic and fluoroscopic images were taken at specific time intervals according to the examination protocol to capture the contrast as it travels through the different system of the organ of interest. This gives a comprehensive view of patient's anatomy and some information on the functioning of the system. Usually, a scout image is taken before the contrast medium is administered.

2.4. Effective dose estimation

ESAK was used to estimate the organ equivalent dose (H) using software provided by the National Radiological Protection Board (NRPB-SR279; Hart et al., 1996). An effective dose is given by the