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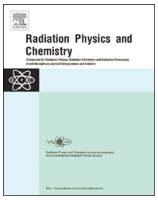

Radiation dose and cancer risk in patients undergoing multiple radiographs in intravenous urography X-ray examinations

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HIGHLIGHTS

- ESAK values were 6.6–15.3 mGy, while cancer induction (4–8) and mortality per million (2–4) varied.
- Reducing radiographs and technique charts are important dose optimization tools.
- Digital techniques improve diagnostic quality and have low costs and complications.

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ABSTRACT

The purpose of the this study was to measure the entrance surface air kerma (ESAK) and body organs, and the effective doses in intravenous urography (IVU) X-ray examinations in Sudanese hospitals. Seventy-two patients who underwent IVU multiple radiographs from five hospitals (six rooms) were examined. ESAK was calculated from incident air kerma (Ki) using patient exposure parameters and tube output $Y(d)$. Dose calculations were performed using CALDOSE X 5.1 Monte Carlo-based software. Risk of cancer induction (4–8) and mortality per million (2–4) varied. The gallbladder, colon, stomach, gonads and uterus received organ doses of 5.3, 3.6, 3.2, 0.61, and 0.8 mGy, respectively. ESAK values ranged from 6.6 to 15.3 mGy (effective doses: 0.70–1.6 mSv). Mean ESAK fall slightly above the diagnostic reference level. Several optimization strategies to improve dose performance were discussed. Reducing the number of radiographs and the use of technique charts according to patient sizes and anatomic areas are among the most important dose optimization tools in IVU.

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1. Introduction

Despite advancements in computed tomography (CT), intravenous urography (IVU) is still the major method used to investigate the urinary track in developing countries. IVU involves multiple radiographs (average of five) of the urinary tract. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) reported that even if IVU frequency is only about 1.3% of the total number of X-ray examinations, its contribution to the collective dose is much higher, equal to about 11%.

Recently, several surveys were carried out in Sudan to study the doses of radiation that patients were exposed to during diagnostic procedures. Doses were studied in conventional radiography (Suliman et al., 2007; Suliman and Elawed, 2013; Suliman and Elshiekh, 2008) and in CT (Suliman et al., 2011). The common purpose of these surveys was to establish a national patient exposure databank, increase radiation protection awareness in the medical field and use the results to formulate national diagnostic reference levels. As a continuation of these efforts, we conducted a dose survey to measure radiation doses received by patients undergoing IVU examinations. Patients undergoing IVU examinations receive multiple X-ray radiographs (average of five) and consequently, radiation risk from these examinations is high.

In a previous study, Halato et al. (2010) reported mean entrance surface air kerma (ESAK) in a complete IVU up to 34 mGy. According to the International Commission on Radiological Protection (ICRP, 2007), radiation deterministic effects are not expected in the absorbed dose range up to around 100 mGy. Therefore, the principal concern for a patient undergoing IVU examination is the risk of developing radiation-induced cancer. According to the

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linear non-threshold, the risk linearly increases with radiation dose. It is important, therefore, that frequent dose surveys are carried out to ensure that patient doses are consistent with relevant international safety standards.

The purpose of this study was to estimate the ESAK for patients undergoing IVU X-ray examinations and the total patient risk, which is related to the effective dose (E) and depends on the dose to each organ and their radiosensitivity (ICRP, 2007). As such, organ and effective doses were calculated as well.

2. Materials and method

2.1. Dose survey

Five hospitals (alphabetically coded from A to E) comprising six X-ray rooms and a sample of 72 IVU examinations in patients were studied. The local ethics committees of all participating institutions approved the study protocol. Informal consent and willingness to participate in this survey was obtained from all study subjects. Using questionnaire forms, information were collected about hospital name, X-ray unit, manufacturer, model, screen type and film speed. Radiographic equipment technical data are given in Table 1.

For patient dose estimates, the following technique parameters were recorded: peak tube voltage (kVp), exposure current–time product (mA s) and focus-to-film distance (FSD). Patient age and weight were also recorded.

All adult patients aged ≥ 16 years with a weight of 70 ± 20 kg were included in this study. Quality control (QC) tests were performed in all departments that participated. Only films that were considered of diagnostic value were accepted in this study in order to ensure that all dose levels used were representative of the diagnostic image.

2.2. Dosimetry software

All doses in this study were calculated using CALDose_X 5.1 software (Kramer et al., 2008) that enables the calculation of incident air kerma (IAK), based on the output curve of an X-ray tube, and of the entrance surface air kerma (ESAK), which is calculated by multiplying the IAK with a backscatter factor. CALDose_X also calculates organ and tissue absorbed doses for the adult posture using conversion coefficients (CCs) normalized to the IAK, ESAK, or the kerma area product (KAP) for standard X-ray examinations. The program provides separate, calculated, and weighted MAX06 and FAX06 whole-body absorbed doses, which represent the sex-specific contributions to the E, which is calculated as the arithmetic mean of the two sex-specific weighted absorbed doses. Furthermore, CALDose_X also determines the risk of cancer incidence and cancer mortality for patients (Kramer et al., 2008).

Table 1
Radiographic equipment technical data.

Hospital	Equipment make/model	Installation	Stated filtration	Film screen type/speed	Tube output at 70 kV (μGy/mA s)
A	Toshiba/LISTEM	2003	0.7	Green/400	35
B	Toshiba/LTN-25	2002	0.7	Green/400	25
C	Toshiba/DR3724H	2004	2.3	Green/400	37
D1	Toshiba/DR3724H	1998	2.3	Green/400	50
D2	Toshiba/DR3724H	1998	2.3	Green/400	50
E	Toshiba/t7239	2004	2.9	Green/400	50

ESAK, organ doses and E were calculated from the typical IVU examinations found in the present work, which compose of four projections: two full view KUB examinations and two of just the kidney (HPA, 2006). CALDose software does not have KUB examinations in its database; therefore, KUB was replaced by abdomen examinations (standard field +2 cm below).

2.3. Dosimetry formulations

In order to calculate ESAK using CALDose_X 5.1 software, we performed X-ray output measurements, $Y(d)$, of all X-rays units in the study. ESAK was then calculated from incident air kerma, Ki, which was determined using patient exposure parameters and tube output $Y(d)$ (ICRU, 2006).

2.3.1. The X-ray tube output measurements

The normalized X-ray tube output, $Y(d, \text{kV})$, is the quotient of the air kerma, Ka, measured at a specified distance, d, from the X-ray tube focal spot (typically 1 m) by the tube-current exposure-time product, P_{It}. Thus

$$Y(d, \text{kV}) = K_a(d, \text{kV})/P_{It} \tag{1}$$

Measurements of Ka(d) were made using a calibrated Unfors Xi dose rate meter (Unfors Inc., Billdal, Sweden). We measured the tube output in the range of X-ray tube exposure conditions met in clinical practice (kV and P_{It}). The values of the X-ray tube output $Y(d)$, were then plotted against the tube potential for all equipment. The resulting curves were fitted using a power function as shown in Fig. 1.

2.3.2. Entrance-surface air kerma (ESAK) calculations

ESAK is defined as the air kerma measured on the X-ray beam axis at the point where the X-ray beam enters the patient or a phantom, including the contribution of the backscatter radiation (ICRU, 2006). CALDose_X 5.1 calculates it as follows:

$$K_i = Y(d, \text{kV}) P_{It} \left(\frac{d}{\text{FSD}} \right)^2 x\text{BSF} \tag{2}$$

where $Y(d, kV)$ is the equipment specific normalized tube output (μGy mA s^{-1}) at 1 m from the focus. It is obtained from Fig. 1 using patient exposure kV, P_{It} (tube-current exposure time product) and focal-to-surface distance (FSD). BSF is the backscatter factor for a particular examination of the required potential and was taken from UK Health Protection Agency HPA (previously NRPB) numerical simulations [NRPB, 1996].

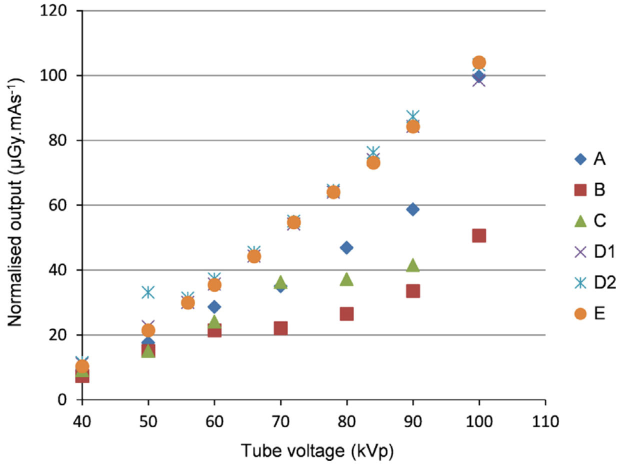

Fig. 1. X-ray tube output, $Y(d)$ (μGy mA s^{-1}) as a function of tube voltage.

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