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RADIATION DOSE LEVELS FOR CONVENTIONAL CHEST AND ABDOMINAL X-RAY PROCEDURES IN ELECTED HOSPITALS IN SUDAN

E. Babikir[1,2,*], Hussein A. Hasan[2], A. Abdelrazig[3], M. A. Alkhorayef[1], E. Manssor[4] and A. Sulieman[4]
[1]Radiological Sciences Department, College of Applied Medical Sciences, King Saud University, P.O. Box 10219, Riyadh 11433, Kingdom of Saudi Arabia
[2]Diagnostic Radiology Department, College of Medical Radiologic Sciences, Sudan University of Science and Technology, P.O. Box 1908, Khartoum, Sudan
[3]Radiation Safety Department, Sudan Atomic Energy Commission, P.O. Box 3001, Khartoum 11111, Sudan
[4]Radiology and Medical Imaging Department, College of Applied Medical Sciences, Prince Sattam bin Abdulaziz University, P.O. Box 422, Alkharj, Kingdom of Saudi Arabia

*Corresponding author: etom@ksu.edu.sa

This study aimed to assess patient entrance surface air kerma (ESAK) during chest and abdominal X-ray procedures in screen film radiography (SFR) and computed radiography (CR) to establish dose reference levels. Patients' doses were measured in five hospitals for a total of 196 patients. ESAK was calculated from exposure parameters using DosCal software. The X-ray tube output (mGy mAs^{-1}), accuracy of exposure factors, linearity and reproducibility were measured using an Unfors Xi dosimeter. The overall mean and range of ESAK during chest X-ray were 0.6 ± 0.3 (0.1–1.3) mGy, while for abdominal X-rays they were 4.0 ± 3.2 (1.3–9.2) mGy. Hospital with a CR system was found to use relatively higher doses. Dose values for abdominal X-ray procedures were comparable with previous studies. The dose for chest X-ray procedure was higher by a factor of 2–3 compared with the current international reference levels.

INTRODUCTION

Medical X-rays are the largest man-made source of public exposure to ionising radiation. Medical imaging procedures contribute about 50 % of the overall radiation dose[(1)]. Chest and abdominal X-rays are the most common procedures in radiology departments worldwide. Chest X-ray procedures account for over 25 % of all X-ray examinations[(2)]. In view of the fact that medical exposure is justified when requested by a qualified medical doctor, with no legally binding dose limit, it is important to avoid unnecessary radiation in order to ensure that the radiation dose is as low as reasonably achievable (ALARA)[(3, 4)]. In addition, regular quality control checks and staff competency are vital aspects of patient dose optimisations. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reported that the patient dose in conventional radiological procedures ranged from 0.1 to 10.0 mSv with wide dose variations among different hospitals[(5)]. Patients received different radiation doses from identical procedures, and variable doses have also been reported in the literature from different hospitals[(6–8)]. These discrepancies in doses were attributed to differences in patient body mass index (BMI), exposure parameters, image receptors, processing conditions and operator competency. Although regular evaluation of patient radiation doses is recommended, only few studies have been conducted regarding this issue. Most of the published studies are from countries of health care level I[(5)]. In Sudan, no diagnostic reference level (DRL) has been adopted to date. Therefore, measurement and establishment of DRLs for radiological examinations are recommended by the international organisations and national regulatory bodies. This study was intended to measure and compare patient radiation doses during chest and abdominal X-rays using screen film radiography (SFR) and computed radiography (CR) imaging systems.

MATERIALS AND METHODS

X-ray machines

Five X-ray systems from different manufacturers were involved in the study. The equipment characteristics, numbers of patients and installation dates are presented in Table 1. The selected departments in Ibnsina (A), Khartoum (B), Bahri (C) and Ribat (D) were equipped with conventional SFR systems, using film speed of 400, and the Royal Centre (E) utilised a CR system. A total of 196 patient examinations were included in the study. Patients were divided into groups according to the X-ray machine used and X-ray procedure.

Equipment quality control (QC)

Basic quality control (QC) tests of the X-ray tube output (mGy mAs^{-1}), exposure factors (kVp, mAs

Table 1. Machines characteristics.

Hospital	No. of Patients	Model	System type	Filtration (mm Al)	Install. date
A	58	Toshiba	SFR	2.9	1994
B	36	Toshiba	SFR	2.5	2007
C	24	Shimadzu	SFR	2.5	2012
D	51	Siemens	SFR	2.5	2004
E	27	Toshiba	CR	2.5	2011

Table 2. Mean and range of patient demographic data for patients undergoing chest radiography.

Hospital	No. of Patients	Age (y)	Height (cm)	Weight (kg)	BMI (kg m^{-2})	Tube voltage (kVp)	Tube current–time product (mAs)
A	48	53.2 (19–80)	167 (148–181)	65 (38–110)	23.3 (15.5–45.8)	71.3 (60–90)	20.9 (8–32)
B	26	51.0 (21–86)	152 (120–200)	75.2 (55–110)	34.2 (19.6–49.3)	71.5 (54–80)	14 (7.2–17.7)
C	14	50.3 (20–75)	164 (150–186)	68.2 (45–90)	25.4 (15–31.2)	73.6 (58–86)	12.7 (5–18)
D	41	42.1 (20–75)	166 (145–180)	67.0 (45–95)	25.0 (14–35)	68.4 (56–82)	16.6 (6–22)
E	17	56.0 (25–80)	166 (150–190)	85.0 (60–120)	31.3 (21–46)	81 (72–90)	17.8 (6–25)

and time) accuracy, linearity and reproducibility were conducted to evaluate the performance according to international standards as baseline for the evaluation of dose levels.

QC tests were performed on the X-ray machines in the selected hospitals in accordance with the recommendations of the American Association of Physicists in Medicine (AAPM) Report 74[9] and the Institute of Physics and Engineering in Medicine (IPEM) Report 91[10]. The QC tests were performed by experts from the Sudan Atomic Energy Commission using Unfors Xi dosimeters (Unfors, Inc., Billdal, Sweden).

Dose calculation

The entrance surface air kerma (ESAK) for patients was assessed by the indirect method, using data of radiation output of the X-ray tubes and exposure factors (kVp and mAs). ESAK (mGy) was calculated using the following equation:

$$\mathrm{ESAK} = \mathrm{OP}\left(\frac{\mathrm{kVp}}{80}\right)^2 \mathrm{mAs}\left(\frac{100}{\mathrm{FSD}}\right)^2 \mathrm{BSF}$$

where kVp is the applied tube voltage, mAs is the applied current to time product, FSD is the focus to skin distance, OP is the radiation output in mGy measured at 80 kVp at a distance of 1 m, and BSF is the backscatter factor.

Measurement of patient dose

A total of 196 patients were examined, 74.5 % underwent chest X-ray procedures and the remaining patients underwent abdominal X-rays. The ethics and research committee approved the study, and informed consent was obtained from all patients prior to the procedure. Patient demographic data [age, gender, weight, height and BMI (kg m^{-2})] were evaluated prospectively using a standard data collection sheet.

ESAK was used to estimate the effective dose (E) using software provided by the National Radiological Protection Board (NRPB-SR262)[11].

RESULTS

The patients' demographic data in terms of age, weight, height and BMI as well as the exposure parameters (kVp and mAs) are presented in Tables 2 and 3. The mean and range of the patients' ESAK (mGy) during chest and abdomen X-ray procedures are presented in Table 4 and Figures 1 and 2.

DISCUSSION

Patient demographic data were comparable in Hospitals A, C and D and were within the normal range of BMI for both procedures, whereas patients undergoing chest X-rays in Hospital B were obese and those in Hospital E were overweight. As a result, exposure factors at Hospitals B and E are higher compared with those at other hospitals (Tables 2 and 3). The results of ESAK (mGy) were considered sufficiently representative for the specific procedures and are shown in Figures 1 and 2. The mean values across the five hospitals for chest and abdominal X-ray procedures were 0.6 $\pm$ 0.3 and 4.0 $\pm$ 3.2 mGy,

Table 3. Mean and range of patient demographic data for patients undergoing abdominal radiography.

Hospital	No. of Patients	Age (y)	Height (cm)	Weight (kg)	BMI (kg cm^{-2})	Tube voltage (kVp)	Tube current–time product (mAs)
A	10	41.2 (18–80)	164 (130–177)	65.5 (40–120)	24.5 (13.8–44.1)	74.8 (65–92)	21.3 (16–32)
B	10	55.6 (35–78)	143.3 (130–160)	65 (50–80)	32.1 (25.4–41)	76 (84–80)	27.3 (16–50)
C	10	21 (18–25)	136 (100–158)	40 (15–55)	19.7 (15–22.2)	67.3 (64–70)	20.3 (16–25)
D	10	56.7 (20–85)	170.7 (160–185)	70 (52–90)	24.4 (19–35.2)	80.4 (75–87)	28 (22–36)
E	10	47.4 (29–75)	171 (160–180)	85.8 (70–100)	29.4 (27.3–35)	80 (80–80)	54 (40–70)

Table 4. Mean and range of the patients ESAK (mGy) and effective dose (mSv) during chest and abdominal radiography.

Hospital	Chest X-ray		Abdomen X-ray	
	ESAK (mGy)	Effective dose (mSv)	ESAK (mGy)	Effective dose (mSv)
A	0. 7 ± 0.3 (0. 2–1.6)	0.17 ± 0.3 (0.03–0.28)	2.4 ± 2.5 (1.4–5.6)	0.2 ± 2.5 (0.12–0.47)
B	0.5 ± 0.5 (0.1–0.7)	0.1 ± 0.5 (0.02–0. 1)	3.6 ± 2.6 (1.9–7.2)	0.32 ± 2.6 (0.17–0.64)
C	0.4 ± 0.3 (0.1–0.8)	0.1 ± 0.3 (0.02–0.13)	1.9 ± 0.7 (1.3–2.5)	0.14 ± 0.7 (0.10–0.19)
D	0.5 ± 0.2 (0.1–0.9)	0.1 ± 0.2 (0.02–0.20)	3.7 ± 0.9 (2.5–5.6)	0.37 ± 0.9 (0.25–0.56)
E	0. 8 ± 0.4 (0. 2–1.3)	0.14 ± 0.4 (0.04–0.24)	6.2 ± 2.3 (2.6–9.2)	0.62 ± 2.3 (0.26–0.92)

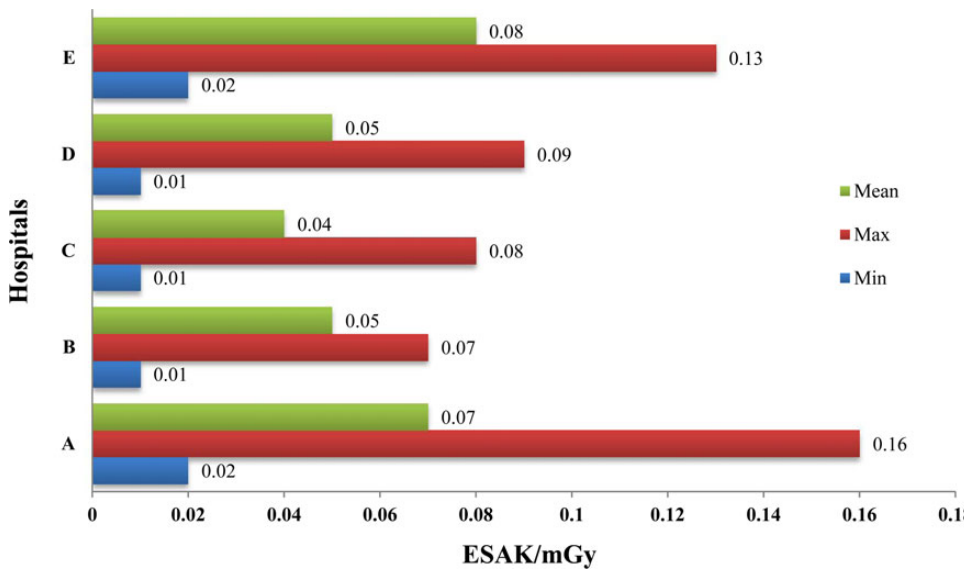

Figure 1. Comparison of ESAK (mGy) during chest X-ray exams in the different hospitals.

respectively, as illustrated in Figures 1 and 2 and Table 4. The mean patient effective doses (mSv) for both procedures were also presented in the same table. The effective dose is used for risk estimation and comparison between different studies when different dose descriptors are used such as kerma area product (KAP). As expected, obese patients were exposed to a higher radiation dose and hence to higher effective doses compared with normal weight patients. Patient doses showed wide variation among the five hospitals

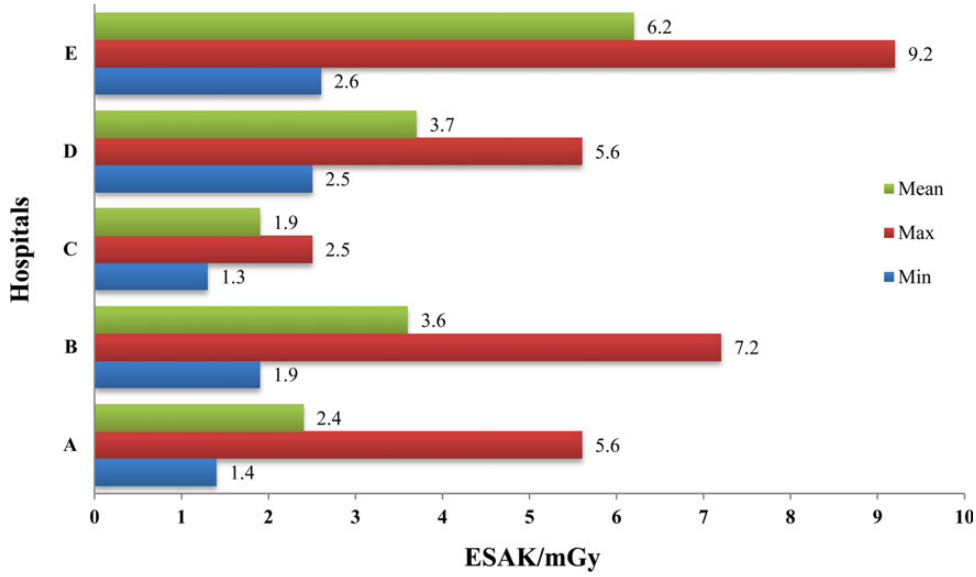

Figure 2. Comparison of ESAK (mGy) during abdomen X-ray exams in the different hospitals.

Table 5. Comparison of mean ESAK for chest and abdominal radiography in this study with DRLs from other studies.

Exam	DRL (ESAK mGy^{-1})					Present study
	AAPM[9]	ICRP[15]	United States[3, 16]	Korea[17]	United Kingdom[18]	
Chest X-rays	0.25	0.4	0.25	0.21	0.15	0.6
Abdomen X-rays	4.5	10	4.5	2.33	4.7	4.0

(Table 4). This variation in ESAK values illustrates that there is a need to establish a DRL for these procedures in order to harmonise the imaging protocol between different hospitals. ESAK values in Hospital E were higher compared with those in other hospitals. This can be attributed to the CR systems used and higher patient weight. The wide dynamic range of a CR system allows a high tolerance for variations in exposure[12]. A wide range of inter-patient dose variations were observed for chest and abdominal procedures.

The difference between minimum and maximum ESAK per procedure values varied up to a factor of 80. The same findings have been reported in the literature[12]. Reasons for these dose variations were complex, but, in general, low tube potential, high mAs and low filtration were associated with high-dose hospitals. Dose variations for each type of examination in the same room were due to the differences in patient demographics and the technique used by different radiographers. Dose variations between different hospitals were due to differences in radiographic equipment, film type and processing conditions. These dose findings were comparable with international DRLs for abdominal radiography as shown in Table 5. The dose value of chest radiography is two times higher than the DRL values reported in Table 5. The mean dose values for chest radiography were comparable with published values for SFR reported by Ciraj *et al.*[13] and Padovani *et al.*[14].

As previously mentioned, these dose values can be attributed to high mAs (21.0–54.0 mAs) used in this study compared with other studies (7.0–20.0 mAs) presented in Table 5. Therefore, increasing the tube filtration and proper selection of exposure parameters (kVp and mAs) are effective methods for reducing patient dose during chest radiography. The improvement in image receptor technology provides potential for dose reduction but requires proper adjustment of exposure parameters and operator skills.

CONCLUSION

The results of this dose survey provide essential data for patient dose levels for chest and abdominal radiography and the performance of the equipment used. Dose values for abdominal radiography were comparable with previous studies. The doses for chest radiography were higher by a factor of 2–3 compared with the current international DRLs. These findings support the importance of the ongoing quality assurance programme to ensure that doses are kept to a level consistent with optimum image quality.

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