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Full Length Research Paper

Diagnostic radiographic examinations in Saudi Arabia based on thermoluminescent dosimetery

Mohamed Anwar K. Abdelhalim

Department of Physics and Astronomy, College of Science, King Saud University, P.O. Box 2455, Riyadh – 11451, Saudi Arabia. E-mail: abdelhalimmak@yahoo.com or mabdulhleem@ksu.edu.sa.

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This study was performed as part of a comprehensive project to establish national diagnostic reference levels (NDRLs), for the first time, in Saudi Arabia. The study consisted of 240 patients who were referred for x-ray examinations at King Khalid University Hospital (KKUH) in Saudi Arabia. Patients' information and exposure parameters for eight of the common x-ray examinations (12 standard projections) were evaluated. The patient mean dose values recorded at KKUH were compared with the corresponding values at other national institutions (Security Forces Hospital and King Abdul-Aziz City for Science and Technology). The patient exposure parameters of several radiographic projections [chest (posterior anterior), skull (anterior posterior/posterior anterior and lateral), cervical spine (anterior posterior and lateral) and lumbar spine (anterior posterior and lateral)] measured at KKUH were compared with their corresponding values at the International Hospitals (Iran, United Kingdom and Malaysia). We found that the patient mean dose values recorded at KKUH varied widely from those recorded at the other national institutions. In addition, the patient exposure parameters recorded at KKUH varied from those measured at the international hospitals. Variations in patient dose arising from a specific X-ray examination may emerge from complex causes, but in general, low peak kilovolt and high milli Amperes were associated with the higher doses. The results of this study will prove useful information for the formulation of NDRLs and also provide local diagnostic reference levels for several diagnostic x-ray examinations at KKUH, other national institutions and international hospitals.

Key words: Harshaw 3500 reader, national hospitals, radiographic examinations, thermoluminescent dosimeters, x-rays.

INTRODUCTION

Various researchers who have carried out national and international surveys have reported wide variations in patient dose arising from specific x-ray examination (Seeram et al., 2006; Toosi and Asadinezhad, 2007, 2008; Lanca et al., 2008). Medical uses of radiation have grown very rapidly over the past decade.

In the US, the average radiation dose to which they are exposed has doubled in the past 30 years. The average dose from natural background sources has not changed, but what has changed is a more than six-fold increase in the average radiation dose from medical imaging. The biggest contributor to this increase in the radiation dose from medical imaging is from CT: In 1980, about 3 million CT scans were done each year in the US, whereas the number now is over 70 million. Radiation doses from CT are typically more than 100 times those from conventional x-ray exams, such as a chest x-rays or mammograms and there is now direct epidemiological evidence of a small but statistically significant increased lifetime cancer risk at CT doses (Brenner et al., 2001).

Many specialized organizations in radiation protection have published recommendations to limit these doses for protection of the patients: International Commission on Radiological Protection (ICRP, 2007), International Atomic Energy Agency (IAEA, 2004) and European Commission (2000). Moreover, most physicians have difficulty in assessing the magnitude of exposure or potential risk. Relatively high values of radiation exposure have been considered a necessary consequence of cardiac angiographic procedures (Cusma et al., 1999; Watson, 1997).

Multislice computed tomography (CT) angiography has been increasingly used in the detection and diagnosis of coronary artery disease because of its rapid technical evolution from the early generation of 4-slice CT scanners to the latest models such as 64, 256 and 320-slice CT scanners. Technical developments of multislice CT imaging enable improved diagnostic value in the detection of coronary artery disease and this indicates that multislice CT can be used as a reliable less-invasive alternative to invasive coronary angiography in selected patients. In addition, multislice CT angiography has played a significant role in the prediction of disease progression and cardiac events. Despite promising results reported in the literature, multislice CT has the disadvantage of having a high radiation dose which could contribute to the radiation-induced malignancy. A variety of strategies have been currently undertaken to reduce the radiation dose associated with multislice CT coronary angiography, while in the meantime acquiring diagnostic images (Zhonghua, 2010).

The radiation risks arising from cardiac CT angiography have raised serious concerns in the medical field as CT is associated with a non-negligible life attributable risk of cancer (Einstein et al., 2007).

An effective dose provides an approximate indicator of potential detriment from ionizing radiation and should be used as one parameter in evaluating the appropriateness of examinations involving ionizing radiation. Standard radiographic examinations have average effective doses that vary over a factor of 1000 (0.01 to 10 mSv) (Fred et al., 2008).

In recent years, these variations in dosimetric quantities observed in various countries have stimulated worldwide interest in patient doses and several major dose surveys have been conducted in many countries (Johnston and Brennan, 2000). National diagnostic reference levels (NDRLs) in Ireland for four of the most common x-ray examinations (chest, abdomen, pelvis and lumbar spine) demonstrated lower reference dose levels of up to 40% when compared with those established by the United Kingdom and the Commission of the European Communities for four out of six projections (Johnston and Brennan, 2000). Only the chest x-ray exhibited a similar reference level to ones established elsewhere. These reports emphasize the need of each country to establish its own reference dose levels to suit its own radiographic techniques and practices in order to optimize patient protection (Johnston and Brennan, 2000; Tung et al., 2001).

The need for radiation dose assessment of patients arising from diagnostic x-ray examinations has been highlighted by increasing knowledge of the hazards associated with the lowest doses of ionizing radiation (Toosi and Asadinezhad, 2007). Thus, the aim of this study was to establish a dosimetric survey (patient information and patient exposure parameters) based on thermoluminescent dosimeters (TLDs) for eight diagnostic radiology examinations of 12 standard projections in Saudi Arabia. The patient mean dose values of several radiographic projections recorded at King Khalid University Hospital (KKUH) in Saudi Arabia were compared with their corresponding values at other national institutions [Security Forces Hospital (SFH) and King Abdul-Aziz City for Science and Technology (KACST)]. The patient exposure parameters of several radiographic projections recorded at KKUH was compared with their corresponding values at the international hospitals (Iran, United Kingdom and Malaysia).

MATERIALS AND METHODS

Preparation of TLDs

TLDs used in this study were TLDs 100 (LiF: Mg, Ti). Their effective atomic number was Zeff 8.2, size was 3.1 mm × 3.1 mm × 0.9 mm, thickness was 0.9 mm and light output was equivalent to that obtained from 89 × 10^{-4} Gy of gamma radiation. They can be used to measure low radiation doses, with a very good linear dose response in the range up to 10 Gy. The thermal luminescent major peak was at a wavelength equal to 4000 A^0 with a negligible fading. The time between irradiation and readout of all dosimeters was consistent in order to keep fading constant from one calibration to the next. The calibration source used in this study was Co-60. The detectors (TLDs-100) were irradiated three times with fixed known radiation dose (mGy). In each time, the irradiated TLDs dose was measured using Harshaw reader.

Reader and dosimeter calibration

The purpose for using the dosimeters was selected by choosing one mode from five modes, which were: anneal dosimeters, generate calibration dosimeters, calibrate dosimeters, calibrate reader and read dosimeters. To anneal the dosimeters, the manual process using a Harshaw 3500 reader and/or an oven was used. To generate a set of calibrated dosimeters, first any residual or spurious thermoluminescent signals were cleared, then they were exposed to a known source of radiation (Saint Gobain Crystals and Detectors, 2001) and then all TLDs were read.

The purpose of reader calibration is to maintain a consistent output from the reader over a period of time based on a convenient local source of radiation. The reader calibration factor (RCF) converts the raw charge data in the photomultiplier tube from nanocoulombs to dosimetric units (mGy). RCF is defined as an average response of the reader to a subset of calibrated dosimeters expressed in dosimetric units. The dosimeters were read for a specific value of irradiation, the units were chosen and then RCF was computed.

The purpose of TLD calibration is to ensure that all dosimeters in a system will give essentially the same response to a given radiation exposure. Due to the natural variation in thermoluminescent material responsiveness and in the physical mass of manufactured thermoluminescent chips, there can be a variation in response of as much as 30% from a mean population of dosimeters. The calibration factor for dosimeters is called the element correction coefficient (ECC). ECC was used as a multiplier with the reader output (in nanocoulombs) to make the response of each dosimeter comparable to an average response of a designated group of dosimeters maintained as calibration dosimeters, where:

$$\text{Exposure} = \text{ECC} \times \text{Charge} / \text{RCF}$$

The mode ‘read dosimeters’ was selected and ‘read’ was selected until all the readings were completed.

Assessment of patient dose levels in several anatomic regions

Routine x-ray examinations were assessed in KKUH, Saudi Arabia. The selection of KKUH to participate in the survey was based on the convenience and willingness of the hospital. The study group consisted of 240 patients who were referred to the Radiology Department at KKUH. The selected radiographic examinations were mammogram [anterior posterior (AP) and oblique (OBL)], skull [posterior anterior (PA)/lateral (LAT)], KUB (AP/LAT), ankle (PA), foot (PA/OBL and LAT/OBL), hand (PA/AP), hip (AP/LAT) and paranasal sinuses (AP) in 12 projections. 20 readings for each specific radiographic examination were studied. Special attention was made to include only the patients whose radiographs were of an acceptable quality.

The consequent emergence of the field of digital radiography (DR) and computed radiography (CR) has completely altered the face of the conventional x-ray imaging modality. In this study film/screen systems were used.

Patients' information (age, gender, weight and height) and radiographic parameters (peak tube voltage (kVp), exposure current-time product (mAs), focus to film distance and film size) were recorded. The measurement of entrance skin doses (ESDs) was made with TLD-100 chips. To anneal the TLD-100 chips, they were heated at 300°C for 1 h and cooled down slowly to ambient temperature. The TLD 100 chips were placed in black plastic to isolate them from any external radiation and stored in a box made from lead. TLD-100 chips were assigned and attached to the patient's body at the center of the x-ray field. Following the x-ray examination, the TLD-100 chips were then returned to the black plastic and read by a Harshaw 3500 reader. A dosimetric survey (patient information and exposure parameters) based on TLDs for eight diagnostic radiology examinations in 12 standard projections were recorded.

RESULTS

In total, 240 patients who were referred for x-ray examinations at KKUH were included in this study. The patients' information and exposure parameters of eight radiographic examinations (12 projections), including the mean hospital ESD values, are summarized in Tables 1 and 2. As can be seen from Table 2, the study group was of mean age from 31.55 ± 2.60 to 50.15 ± 3.53 years, mean weight from 61.75 ± 3.11 to 76.05 ± 3.05 kg and mean height from 153.20 ± 3.41 to 161.40 ± 1.56 cm.

Patient dose values recorded at two other national institutions (SFH and KACST) are summarized in Table 3. The results from this study demonstrate that patient dose values recorded at KKUH varied from those recorded at SFH and KACST. The patient exposure parameters of several radiographic projections recorded at KKUH were compared with their corresponding values at international hospitals (Iran, UK and Malaysia) (Table 4). As can be seen from Table 4, the mean values of potential, current and ESD determined in this study were compared with the corresponding values reported in Iran (Toosi and Asadinezhad, 2007), the United Kingdom (Hart et al., 2002) and Malaysia (NG et al., 1998). The results in Table 4 indicated that the range of applied tube potential for all the projections at KKUH was higher than the corresponding range reported in the surveys undertaken in Iran, United Kingdom and Malaysia. It was found that KKUH current values in most projections were lower than those detailed in the other surveys. Furthermore, the mean ESD values for all the projections included in this study were much lower than the corresponding values noted in the other surveys. Tables 3 and 4 show gaps in the data for the other hospitals compared in this study. Can this lack of data be improved or obtained?

The lack of data in Tables 3 and 4 may be attributed to the lack of published data related to the common x-ray examinations in standard projections.

DISCUSSION

The results of this study demonstrated that patient dose values recorded at KKUH varied from those recorded at SFH and KACST. The very wide variations in patient dose arising from a specific type of x-ray examination in different national and international hospitals suggest that significant reductions in the patient dose would be possible without affecting image quality. Various researchers who previously carried out national and international surveys also reported wide variations in patient dose arising from specific x-ray examination (Seeram et al., 2006; Toosi and Asadinezhad, 2007; Asadinezhad and Toosi, 2008). They suggested that the possible causes for varying patient dose levels could be the examination technique, clinical condition, skill of the radiologist, tube current, tube potential and focus to film distance.

Despite promising results reported in the literature, multislice CT has the disadvantage of having a high radiation dose which could contribute to the radiation-induced malignancy. Healthcare facilities worldwide are now following the global trend by gradually replacing film/screen radiography systems with digital radiography systems, to make images faster, easier and less expensive as well as to obtain, review, duplicate, share and store.

The wide variability found in the patient exposure parameters recorded at KKUH and in Iran, the United Kingdom and Malaysia may also be explained by differences in radiographic parameters [peak tube voltage (kVp), exposure of current-time product (mAs) and focus to film distance]. Specifically, at KKUH, the higher potential values and the lower current values allowed a considerable dose reduction without loss of image quality. Indeed, it has previously been reported that higher potential values allow considerable dose reduction without sacrificing image quality (Lanca et al., 2008).

It has been reported that indirect conversion flat-panel detectors showed the highest potential for reducing exposure, regardless of the clinical setting. There have also been numerous studies comparing various digital detectors within the same application. The authors of

Table 1. Patient information of the eight radiographic examinations (12 projections) at KKUH.

Radiograph	Projection	Age (year)	Weight (kg)	Height (cm)
Mammogram	AP	47.45 ± 0.88	74.85 ± 3.07	160.15 ± 1.03
	OBL	47.85 ± 0.93	72.80 ± 2.80	160.55 ± 1.11
Skull	PA	31.55 ± 2.60	66.70 ± 3.51	155.70 ± 0.90
KUB	AP/LAT	47.35 ± 3.22	70.85 ± 2.90	160.10 ± 1.22
Ankle	AP	41.90 ± 4.10	76.00 ± 5.05	161.40 ± 1.56
	LAT	40.45 ± 4.52	61.75 ± 3.11	160.70 ± 1.69
Foot	AP/OBL	42.75 ± 3.15	67.25 ± 2.60	158.80 ± 1.31
	LAT/OBL	44.70 ± 4.04	67.50 ± 3.28	157.10 ± 1.68
Hand	AP/PA	44.05 ± 3.65	76.05 ± 3.05	158.75 ± 1.11
Hip	AP	46.70 ± 3.63	70.10 ± 4.36	155.40 ± 2.73
	LAT	50.15 ± 3.53	71.45 ± 4.34	153.20 ± 3.41
Paranasal sinuses	AP	34.05 ± 2.57	67.20 ± 3.70	154.75 ± 1.07

Data were recorded at KKUH as mean ± standard error (n = 20 for each radiographic projection).

Table 2. Patient exposure parameters of the eight radiographic examinations (12 projections) at KKUH.

Radiograph	Projection	Focus to film distance (cm)	Potential (kVp)	Current (mAs)	ESD (mGy)
Mammogram	AP	52.45 ± 1.70	28.30 ± 0.23	67.85 ± 5.55	1.361 ± 0.310
	OBL	67.95 ± 2.03	30.02 ± 0.23	86.13 ± 5.97	1.731 ± 0.370
Skull	PA	180.30 ± 1.90	80.00 ± 0.00	18.73 ± 0.92	0.119 ± 0.020
KUB	AP/LAT	107.89 ± 1.53	75.00 ± 0.00	52.22 ± 13.57	0.802 ± 0.140
Ankle	AP	102.08 ± 1.34	66.00 ± 1.34	6.36 ± 0.49	0.174 ± 0.040
	LAT	100.61 ± 1.40	65.80 ± 0.55	5.55 ± 0.31	0.117 ± 0.020
Foot	AP/OBL	104.63 ± 1.70	60.00 ± 0.00	5.68 ± 0.61	0.116 ± 0.020
	LAT/OBL	105.13 ± 1.08	60.00 ± 0.00	5.43 ± 0.36	0.139 ± 0.040
Hand	AP/PA	93.16 ± 0.63	53.00 ± 0.00	3.73 ± 0.27	0.089 ± 0.020
Hip	AP	103.47 ± 1.25	80.00 ± 0.00	18.67 ± 3.09	0.567 ± 0.150
	LAT	102.92 ± 1.60	80.00 ± 0.00	18.37 ± 4.22	0.518 ± 0.110
Paranasal sinuses	AP	176.85 ± 0.54	79.00 ± 0.46	26.53 ± 1.88	0.146 ± 0.040

Data were recorded at KKUH as mean ± standard error (n = 20 for each radiographic projection).

Table 3. Patient mean dose value recorded at different national institutions in Saudi Arabia.

Radiograph	Projection	KKUH (mGy)	SFH (mGy)	KACST (mGy)
Mammogram	AP	0.119 ± 0.020	_	5
	OBL	0.802 ± 0.140	_	10
Skull	PA	0.174 ± 0.040	_	10
KUB	AP/LAT	0.117 ± 0.020	_	_
Ankle	AP	0.116 ± 0.020	0.06	_
	LAT	0.139 ± 0.040	0.08	_
Foot	AP/OBL	0.089 ± 0.020	_	_
	LAT/OBL	0.567 ± 0.150	2.77	10
Hand	AP/PA	0.518 ± 0.110	1.83	_
Hip	AP	0.146 ± 0.040	_	5
	LAT	0.119 ± 0.020	_	5
Paranasal sinuses	AP	0.802 ± 0.140	_	10

Data were recorded at KKUH as mean ± standard error (n = 20 for each radiographic projection).

Table 4. Patient exposure parameters for KKUH and international hospitals.

Radiograph	Projection	Parameter	KKUH	Iran	United Kingdom	Malaysia
Chest	PA	Potential	90	61	58	79
		Current	6	21	5	9
		ESD	0.13	0.37	0.15	0.28
Skull	AP/PA	Potential	80	62	72	71
		Current	19	51	30	38
		ESD	0.12	2.79	2.30	4.78
	LAT	Potential	-	58	66	68
		Current	-	44	19	32
		ESD	-	1.57	1.20	3.34
Cervical spine	AP	Potential	75	62	-	66
		Current	18	29	-	16
		ESD	0.17	1.67	-	1.02
	LAT	Potential	76	59	-	69
		Current	14	17	-	20
		ESD	0.20	0.83	-	1.60
Lumber spine	AP	Potential	79	70	77	77
		Current	28	58	42	51
		ESD	0.65	3.41	5.00	10.56
	LAT	Potential	85	80	88	89
		Current	42	81	72	72
		ESD	1.17	9.03	11.70	18.60

Potential is expressed in kVp, current time expressed in mAs and ESD expressed in mGy.

these studies also concluded that flat-panel detectors achieved the best results in low-exposure imaging, followed by other DR systems such as selenium drum and CCD-based systems (Veldkamp et al., 2006; Kroft et al., 2005).

A lack of implemented local/national recommendations may be another possible cause. In Portugal, a wide variability in patient dose values due to a lack of implemented local/national recommendations, as well as a lack of criteria for good radiographic techniques was reported (Lanca et al., 2008). Implementation of national references could achieve an ESD reduction of between 30 and 60% below the Commission of European Communities (CEC) recommendations (Vano et al., 2002). Several studies have shown that it is possible to achieve a dose reduction of 50% without losing image quality when CEC guidelines are well established (Saure et al., 1995).

Also, there is no report of whether KKUH or the other national and international hospitals are using conventional film/screen or computed and digital radiography methods. KKUH and/or the other national and international hospitals are using conventional film/screen and computed or digital radiography methods.

It would be useful for KKUH to formulate its own local DRLs from the ESD data obtained and then compared with other local or international DRLs. This study was performed as part of a comprehensive project to establish NDRLs, for the first time, in Saudi Arabia. Moreover, it consisted of 240 patients who were referred for eight of the common x-ray examinations (12 standard projections: patient information and exposure parameters) at KKUH in Saudi Arabia.

Local recommended DRLs for the eight radiographic projections are shown in Figures 1 and 2. In addition, it could improve lack of criteria for good radiographic techniques as well as it could achieve an ESD reduction in patient doses below the Commission of European Communities (CEC) recommendations.

Conclusions

The data of this study will be useful for the formulation of NDRLs and also provide local diagnostic reference levels for several diagnostic x-ray examinations at KKUH and other national institutions in Saudi Arabia.

The results of this study show that at a national level,

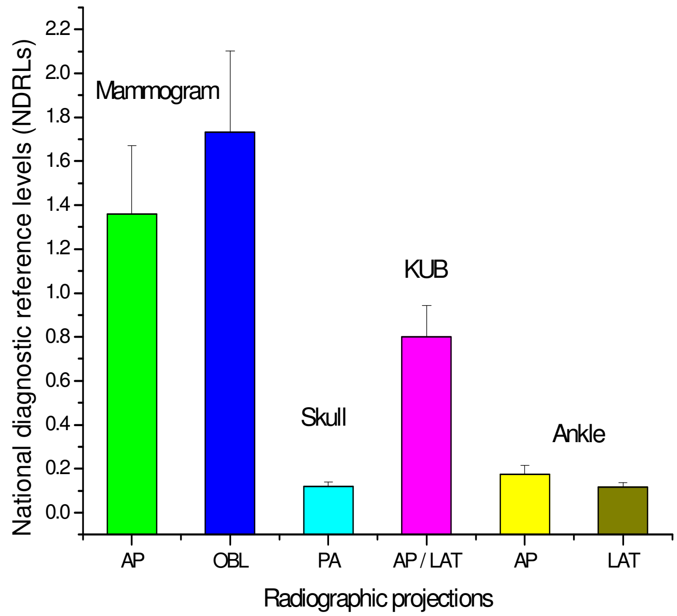

Fig. 1. Local DRLs for the 4 radiographic projections.

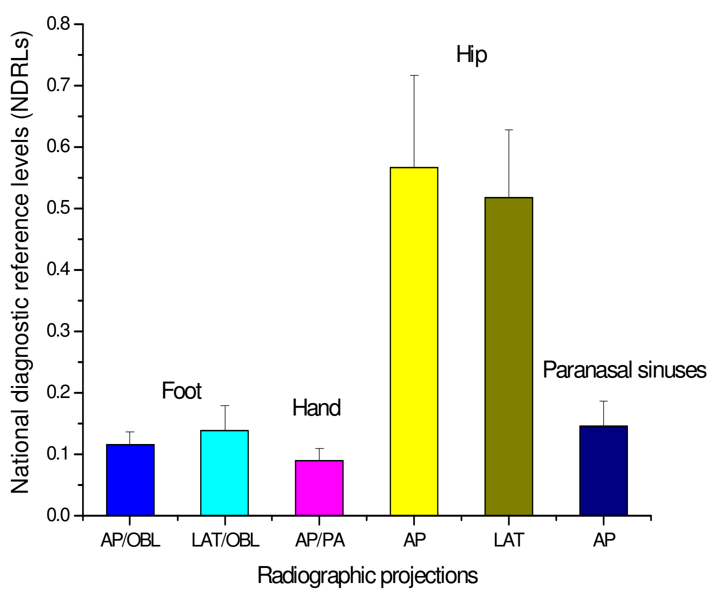

Figure 2. Local DRLs for the 4 radiographic projections.

radiographic practice does not comply with CEC guidelines concerning exposure techniques of 1985. Further national studies are recommended with the objective to improve exposure optimization and technical procedures in radiographic examinations. Moreover, digital radiography has the potential to offer greater productivity, improved efficiency and more accurate diagnoses.

Further studies will be taken into consideration to get national DRLs after exposure optimization.

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